Smith's Textbook of
ENDOUROLOGY

3rd Edition

VOLUME ONE

EDITED BY
Arthur D. Smith
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Smith's Textbook of Endourology

VOLUME I

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Foreword

"End of Urology," so spoke the late Richard Williams, my good friend and colleague, when as residents we witnessed a newly arrived faculty* at the University of Minnesota begin to do with tubes and wires through small holes what we could do so much more adeptly and expeditiously through our macho incisions. "A flash in the pan," so commented the renowned Victor Politano at a meeting in the mid 1980s where Endourology was being presented. "Small incisions are for small surgeons," – the words of surgeon advocates of the massive incision because exposure was king and, after all, incisions healed from "side to side."

"Endourology" was the branding brainchild of Elwin Fraley, Arthur Smith, and Paul Lange. Most felt that the Minnesota cold had finally gone beyond their defenses to create a "brain freeze" of monumental proportions. Fast forward 30 years and, today, Endourology has become Urology. From the urethral meatus to the uppermost renal calyx, the entire urogenital tract is endoscopically accessible and radiologically visualizable. From the smallest to the most complicated open procedure, urologists of talent, innovation, and persistence have supplanted standard incisional access with the endoscope or image-guided therapy. This is the age of surgical nihilism and Endourology has been at the forefront from day one.

If you are reading this foreword, then you hold in your hands a book (or CD) that contains every aspect of Urology and how it is impacted by a minimally invasive approach, be it percutaneous, ureteroscopic, laparoscopic, robotic, or image-guided. The authors are a Who's Who of experts in endourology on a global scale. The content ranges from basic to futuristic Endourology. The latest advances in supine percutaneous stone removal, endoscopic nephrostomy, laparoendoscopic single site surgery as well as natural orifice transluminal endoscopic surgery are clearly detailed and illustrated both in still photographs and often by instructional video demonstrations.

A wise mentor* once informed me that "You are only as good as tomorrow." That single daunting sentence should haunt each of us as we arise every morning to provide relief to those who suffer. To that end, we must seek methods to relieve suffering without causing it, to heal without harming, to cure without creating another, sometimes worse, malady. Endourology empowers every urologic surgeon with the knowledge and tools to provide all individuals seeking our care with a kinder gentler solution to their problem…one that neither disfigures nor maims in the name of treatment. In the words of Sir William Osler "Diseases that harm, require treatments that harm less." A century later, his dictum has become commonplace practice for the endourologist.

My heartfelt congratulations go out to Drs Smith, Badlani, Kavoussi, and Preminger – friends all – to me, to you, and to your patients. So read *Smith's Textbook of Endourology* well, apply its principles earnestly, and if opportunity presents, seek to innovate and improve. The text is not an end in and of itself, rather it is another paver in the surgical journey in which each of us plays a role – using techniques born of today's technology to ever reduce the burden of the "surgical" cure.

Ralph V. Clayman

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*(Arthur D. Smith)

Preface

In 1978 the concept of Endourology was launched. It was defined as closed controlled manipulation within the urinary tract. The word "closed" was used to indicate either a minimal incision or no incision at all and the "control" was achieved either endoscopically or by non-invasive imaging. Until then, residents had been taught that the only way to get good exposure was through a large incision and now the ultimate goal is good exposure with no incision at all. It is achieved with a combination of endoscopy and all the new modalities of imaging. Now there are relatively few accepted open urological surgical procedures and this has had the gratifying result of a dramatic decrease of the morbidity in our patients recuperating after treatment. Because the field has expanded exponentially over the past three decades, the need has arisen for a new updated edition of this textbook.

From the outset, it has been policy of Endourologists to embrace, and evaluate fairly, all new tools and equipment. Consequently we have always been at the cutting edge of new technology. As technology has evolved, courses have been organized, to train not only residents and fellows, but also the practicing urologist, so that their learning curve has been accelerated enabling them to practice endourologic techniques comfortably and with the required expertise. The number of stone cases treated by open surgery today is minimal. Similarly open nephrectomy has almost exclusively been replaced by laparoscopic, robotic or percutaneous ablative techniques.

In this era of fewer working hours for residents, the amount of time that the residents spend in the operating room has decreased dramatically, and the necessary skills have to be taught using a combination of additional educational modalities. In addition to books and journals, there are an abundance of videos on surgical techniques, animal laboratories, teaching models and virtual reality simulators. Fortunately endourologic techniques are uniquely suited to these modalities and the student can become quite adept before being instructed in the operation room. These learning tools have helped urologists all over the world to become competent endourologists.

This 3rd edition has been completely re-written as the field has expanded to incorporate so many applications. The contributors to each chapter are either the innovators of the procedure they describe or alternatively have had vast experience with that technology. Wherever possible we have included videos to enhance the description of the various techniques and the readers will have the opportunity to watch experts doing the procedures. These videos are on portable computer discs which can be seen shortly before any intended endourologic operation as a "re-fresher."

The "Textbook" consists of 2 volumes – the 1st one on stones in the upper tract and the 2nd on laparoscopic and robotic surgery, image guided diagnostics and therapeutics and minimally invasive therapy of the lower urinary tract. The 1st volume has 5 parts:

Section 1 discusses basic principles of the care of instruments, how to protect oneself from radiation exposure, video imaging and documentation which has become so important in the area of electronic medical records. As gram negative septicemia is still prevalent in the management of stone patient's , antibiotic usage in the prevention of sepsis is included in the section. There is a chapter on anti-coagulant therapy which is so prevalent today in patients with coronary artery stents.

Section 2 is devoted to percutaneous renal surgery, from pre-operative evaluation to access, stone removal, other uses of the nephrostomy tract and the exit strategy and complications.

Section 3 discusses all the intricacies of ureteroscopy and Section 4 is devoted to shock-wave lithotripsy. We were cognizant that there is no single modality for treating stones and hence Section 5 describes the management of the patient with various stone related problems in a composite format.

As there is so much overlap between laparoscopic and robotic surgery we combined them in Section 6. At present, the dividing line between the techniques is primarily related to technical experience and availability of the robot together with financial considerations.

Section 7 which discusses image-guided diagnostics and therapeutics, is an important addition to this textbook on Endourology as it is an essential component of the armamentarium of the practicing urologist.

We are moving into an era of "no incisions", and if the procedures described in this section are not performed by urologists, they will be taken over by radiologists. This would result in the loss of continuity of care of our patients.

Finally, Section 8 discusses management of the lower urinary tract. Emphasis has been placed on many ambulatory procedures, as this is an escalating trend endorsed by medical insurance plans.

I would like to thank each of the contributors for the many hours they devoted to writing, illustrating and creating videos for their chapters.

Hopefully they will be as delighted with the results as the editors and publishers of this "Textbook." I am also deeply indebted to my co-editors who have reviewed edited and re-reviewed chapters countless times. I thank not only them but their families as well, for the time spent on the book could have been devoted to them.

The staff at Wiley-Blackwell have been highly efficient, professional and encouraging. When one deals with a large organization it is reassuring to know that as the book passes from one stage to the next and hence to separate departments there is "continuity of care" throughout the operation. They are a great team and we, the editors, appreciate all the help we received from them.

Finally I would like to thank my wife, Kay, who inspired me to edit this 3rd edition and has repeatedly helped me with this text and countless other projects throughout my academic career. If I am regarded as the "father" of Endourology, she is unquestionably the "mother" that helped nurture this field of urology.

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SECTION 1
Basic Principles

CHAPTER 1

Care and Sterilization of Instruments

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History of sterilization

Surgical instruments have been in use since prehistoric times. The effects of using instruments that were neither clean nor sterile were not a major concern in past eras. The methods for the care and sterilization of instruments have gone through an evolutionary change and have greatly improved over the last few centuries. It was not until the 19th century that a process for instrument sterilization was developed and recognized. During this time the focus on the need to sterilize instruments prior to a surgical procedure developed from the effects of postsurgical wound management and the need to eliminate the increased infections of these wounds. This recognition led to the evolution and development of the current standard practice of instrument sterilization.

Noted in the 19th century, surgeons performed operations in their street clothes, often times dirty street clothes, and reused instruments without a standard cleaning process. In 1864, Joseph Lister introduced the use of phenol, a carbolic acid, on inanimate objects and surfaces as well as human tissue, in the hospital wards and operating rooms, which resulted in a dramatic decrease in the incidence of wound infections. Carbolic acid was used in conjunction with other components to dress wounds in an antiseptic manner, which prevented bacteria from entering the wound. This led him to introduce other methods of asepsis, such as sterilization of surgical instruments by using an application of heat and carbolic acid, and the frequent cleaning of the surgeon's hands during an operation. After publication of these findings in the *The Lancet* in 1867, the "era of antiseptic surgery" was introduced into the field of medicine and surgery. By the year 1875 Lister's principles of antiseptic surgery were accepted worldwide [1, 2].

The steam autoclave was derived from a steam digester, currently known as a pressure cooker, invented by the physicist Denis Papin in the late 1600s. By 1879, Charles Chamberland, a colleague of Louis Pasteur, made improvements to Papin's invention and invented a porcelain dish with tiny holes that was able to filter microorganisms from liquid that was poured through this dish. This is known as the Chamberland filter or the Chamberland–Pasteur filter, and with his further research in 1884 the autoclave was invented. The use of pressurized steam sterilization of instruments with an autoclave was introduced by Ernst von Bergmann in 1886.

Ethylene oxide (ETO) was first used for sterilization in 1938 to preserve spices. In the 1950s, ETO was accepted by the medical device industry as a sterilant after a US army researcher investigated the microbicidal effect of ETO and published his findings [3].This method of sterilization has been used for heat-sensitive instruments, such as flexible scopes and lenses.

In the early 1900s, urologic instruments were sterilized in a formalin sterilizer and disinfected with a carbolic acid solution. The formalin sterilizer exposed instruments to heated formalin vapors for 2 h and remained in the sterilizer until use [4].

Since the late 1980s, other methods of sterilization have been developed that are less caustic to instruments, require shorter process time, are noncarcinogenic, and allow for sterile instrument availability. These methods have replaced some of the older sterilization methods.

Instrument processing

Any item, such as an instrument or medical device, that is intended to be reused in a sterile procedure, must be processed in a specific manner, beginning with cleaning

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and ending with sterilization or high-level disinfection (HLD). In order for sterilization or HLD of an item to be effective, the following steps must occur in a proper and adequate manner; cleaning, decontamination, and manual drying. The method of sterilization or HLD will determine the necessary type of package or container the item will be placed in or, in some instances, the item may be placed in storage until reuse.

First the item should be categorized to determine which type of disinfection or sterilization method is recommended for processing. Earl H. Spaulding in 1968 categorized medical instruments and items used for patient care as critical, semicritical and noncritical, based on the degree of risk for infection with the processing and reuse of each item. These categories make up the Spaulding scheme or Spaulding classification, which is a recognized resource when describing the appropriate disinfection and sterilization process for medical instruments and devices [5, 6]. Critical items are instruments that will come in direct contact with sterile tissue, or enter the vascular system, or penetrate skin, and require sterilization by methods of steam, ETO, hydrogen peroxide gas plasma, or a liquid chemical sterilant such as peracetic acid. Semicritical items are instruments that will come in contact with mucous membranes and require sterilization or at a minimum HLD. Noncritical items are instruments or medical devices, such as a stethoscope or blood pressure cuff, that will come in contact with intact skin only and require intermediate-to-low level disinfection, such as an impregnated antimicrobial wipe [6–8].

Utilization of a reusable instrument or medical device is a major risk due to the potential introduction of pathogenic microorganisms which can lead to infection. Therefore, adequate cleaning is imperative to successfully eliminate the amount of bioburden or microbes present on an instrument. Cleaning and decontamination of any level item used in any type of healthcare facility is a mandatory requirement prior to reuse. Each facility must have a policy and procedure manual in place which identifies the process of cleaning or decontamination, followed by the process for disinfection or sterilization of these items.

Cleaning is the most important step in the process leading to sterilization or HLD and begins with physically removing microbes in preparation for the next step, which is decontamination [7]. There are different accepted methods for cleaning instruments prior to disinfection or sterilization, known as manual or automated with a washer/sterilizer, ultrasonic cleaner, or washer/decontaminator [9].

Prior to the cleaning process, any personnel must don protective personal equipment (PPE), including eye protection (goggles, mask with shield), mask, impervious apron, and gloves to avoid exposure to microorganisms and for personal safety protection [9].

The process of manual cleaning involves three components; detergent or enzymatic cleaner, a brush or sponge, and friction [10]. These components will ensure the removal of tissue and debris from an instrument. Manual cleaning of an item begins with immersion in a receptacle or deep sink filled with a detergent or enzymatic cleaner and warm water. Preparation of the detergent or enzymatic cleaner must follow the manufacturer's instructions to ensure the solution is the correct concentration. Many cleaners are designed with a premeasuring pump mechanism; personnel must make certain a full depression of the pump occurs to ensure appropriate solution concentration. A weak solution may fail to break down proteinaceous tissue or a strong solution may create sudsy bubbles which form air pockets and can prevent surface contact by the cleaner. To accurately fill the receptacle or sink with the correct amount of water, a fluid depth indicator or line should be placed for guidance of accuracy [10, 11]. An example is shown in Figure 1.1. A visible instruction guide should indicate the correct solution amount to be added to the correct measurement of water, e.g. 1 ounce of detergent to 1 gallon of water (Figure 1.2).

Prior to immersion, if the item has numerous parts, it must be disassembled, or a hinged instrument must be kept in the open, unlocked position. Gentle scrubbing of the item with a soft bristle brush or sponge will assist removal of bioburden and preservation of the instrument's functions and effectiveness [9]. To prevent aerosol formation from microorganisms, the item being cleaned should be kept immersed below the water level [7]. The next step in manual cleaning is to thoroughly rinse the item with cool water in a deep sink to allow for ample movement. Following the rinse process, sufficient drying time is needed before the item is prepared for sterilization or HLD.

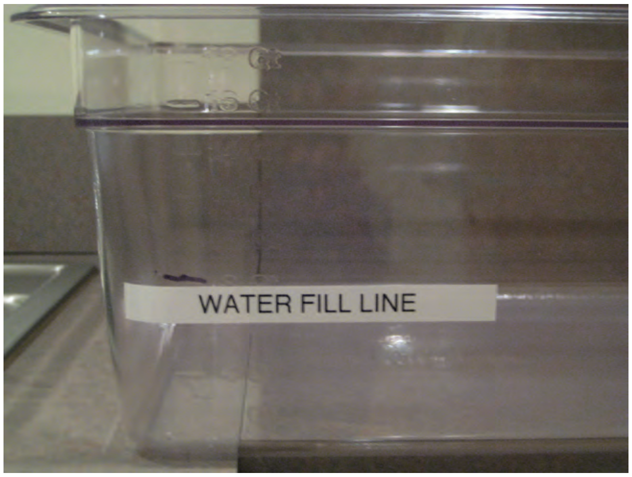
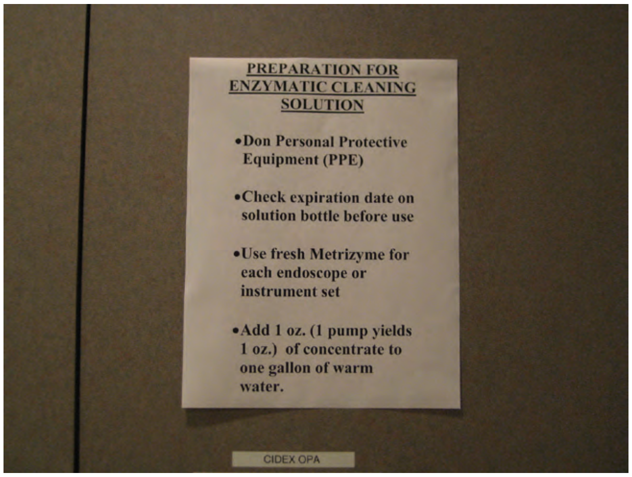


Figure 1.1 Example of the fill line of a cleaning receptacle.



PREPARATION FOR ENZYMATIC CLEANING SOLUTION

- Don Personal Protective Equipment (PPE)
- Check expiration date on solution bottle before use
- Use fresh Metrizyme for each endoscope or instrument set
- Add 1 oz. (1 pump yields 1 oz.) of concentrate to one gallon of warm water.

CIDEX OPA

Figure 1.2 Visible instruction guide for preparing an enzymatic cleaner.

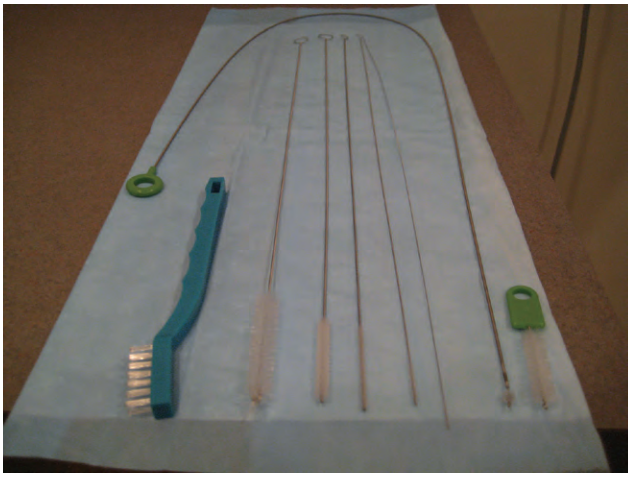


Figure 1.3 Examples of various cleaning brushes.

In urology, endoscopes, flexible or rigid, are frequently used, valuable diagnostic tools, which are reusable and require personnel to follow the guidelines for reprocessing to prevent an outbreak of infections due to improper cleaning. When indicated, a leak test should be performed on all flexible endoscopes prior to full immersion of the scope in the cleaning solution. External surfaces should be washed with a soft brush or sponge to remove any visible debris. Careful attention should focus on the lumens and working channels of all endoscopes. Lumens and working channels should be irrigated with a large syringe or a manufacturer designed irrigating device, first with detergent or enzymatic solution to help remove any residue, and then with a water rinse until it appears clear. Using an appropriate size flexible brush will allow for proper through-and-through cleaning of the lumens and working channels. Brushes are available in a variety of sizes and shapes to accommodate any manufactures' endoscopes, and proper selection is essential for prevention of damage to the endoscope (Figure 1.3). A newly prepared cleaning solution prior to each endoscope cleaning is most effective and helps prevent cross-contamination [10, 11].

A washer/sterilizer is designed to have several cycles, starting with a cold water prerinse, followed by a high temperature wash cycle with an alkaline low sudsing detergent, next a neutralizing cycle, followed by a final rinse, steam sterilization, and a drying cycle [8, 9]. An ultrasonic cleaner functions by a process of cavitation. Ultrasonic energy is passed through a water bath, creating microscopic bubbles that implode. The implosion process creates a suction action that pulls soil and foreign body matter away from instrument surfaces [8, 9]. The washer/decontaminator is a single or multichamber unit that cleans using an alkaline low sudsing detergent with a spray force action and heat for the drying cycle. The multichamber unit allows for multiple single tasks to be performed simultaneously, including a cool water rinse, prewash with an enzymatic cleaner, wash cycle with detergent, ultrasonic cleaning, pure hot water rinse, and high temperature dry time [8, 9].

Protection, handling, and maintenance of instruments

Protection, proper handling, and maintenance of instruments is vital in maintaining the efficacy of instruments, as well as keeping instrument replacement costs down [12]. During and immediately following a procedure, heavily soiled instruments should be immersed in warm water to prevent the onset of corrosion, pitting, and rusting [9, 12].

Proper handling of instruments is a crucial part of instrument maintenance generally. This is frequently overlooked with instruments handled in a careless manner. Any delicate instrument such as telescopes, flexible scopes, light cables, and fine instruments, such as microinstruments, must be handled in a specific manner. During a procedure these instruments should be kept in a separate location on the sterile field to avoid other instruments from being placed on top of them and causing potential damage. When transporting these delicate instruments to the soiled processing room, either they should be carried one at a time or in a specific container designed for instrument transport. Flexible scopes and light cables must not be over coiled while on the sterile field or during transport; this will help prevent the internal fiberoptics from being cracked.

After the cleaning process, instruments should be checked for their function and lubricated when recommended by the manufacturer with a water soluble lubricant [5]. Lubrication also helps prevent rusting and maintains the function of any movable piece, such as a luer lock part.

Methods of sterilization

Sterilization can be achieved by several approved methods. These include using steam, ETO gas, peracetic acid, or hydrogen peroxide gas plasma. Each method has its advantages and disadvantages, along with specific indications for use. The manufacturer's guidelines for any instrument must be followed when selecting which method to use to ensure instrument viability and appropriate sterilization [13]. The healthcare setting will determine which method is suitable for the facility's operational workflow. Monitoring and documentation of the effectiveness of any sterilization method is a mandatory requirement and must be followed according to the facility's policy and procedure guidelines.

Steam sterilization

The process of steam sterilization occurs in a steam autoclave unit designed to produce boiling water equaling 121° and 132°C. The water along with pressure of 15 pounds per square inch (PSI) further produces steam to penetrate packaged or wrapped instruments, or instruments in sterilization containers, to kill any microorganisms present, including spores [14]. In order for steam sterilization to be successful, the following standards are required, exposure to direct pressurized steam, a specific temperature, and a specific length of time [5].

There are different methods of cycle performance with a steam autoclave. One is the gravity-displacement cycle, which removes air by the force of gravity from the top downward. Another is the prevacuum cycle, in which air is removed via a vacuum pump, also referred to as dynamic air removal [5]. The temperature and exposure time vary depending on the type of autoclave unit and the contents of the load.

The common cycle consists of 15 min of preheat, 15 min of pressurized steam, and 5–15 min of cooling [14]. The process of steam sterilization has been in existence for a long time and is recognized to be one of the most effective, safe, and economic sterilization techniques [15].

One major disadvantage of steam sterilization is the inability to sterilize heat-sensitive materials, such as plastic or some rubber materials. Some advantages are its short process time, allowing a quicker turnaround of packaged items, and its availability in various sizes, including one that allows it to be placed on a table top in an office setting, allowing it to be used in any healthcare setting.

Ethylene oxide

ETO has the ability to sterilize heat- and moisture-sensitive instruments and medical devices, such as ones made of plastic or rubber, flexible scopes, and other instruments with lenses. ETO sterilization is a lengthy process, lasting 12 h or longer, which decreases the availability of the instruments. The process must be carried out in an area with proper ventilation, vent-failure alarms, and a special sterilization chamber. ETO concentration must be carefully monitored in work areas to prevent potential injury to staff. Due to ETO's high flammability, it has been mixed with inert gases, such as carbon dioxide or a fluorinated hydrocarbon, to decrease the risk of fire. Freon 12 is a hydrocarbon which has been found to be a major contributor to the destruction of the earth's ozone layer. Since 1998 there has been a significant decrease in the use of ETO for sterilization, since other methods have been introduced [15]. Other disadvantages of ETO are its potential to cause harm to personnel if there is exposure, either acute or chronic. Irritation to the eyes or skin may occur from acute exposure. Chronic exposure may lead to hematologic changes, increased risk of spontaneous abortions, and various cancers [5].

Peracetic acid

In 1988 the introduction of sterilization with a peracetic acid compound provided a new method for medical and surgical instruments, including endoscopes and instruments with lumens. Peracetic acid is an oxidizing agent composed of acetic acid, hydrogen peroxide, and water, but has the disadvantage of being corrosive [16]. To allow for sterilization with peracetic acid, the STERIS Corporation in Mentor, Ohio, USA manufactured a sterilant of 35% peracetic acid and a noncorrosive chemical. This sterilant is packaged in a sealed, single-dose container, and is designed to be used in the manufacturer's table-top sterilizer. This system is to be utilized for "just-in-time" use, therefore it does not require instruments to be wrapped or packaged. The table-top system has covered tray inserts to accommodate various sizes of flexible endoscopes, rigid endoscopes, and other instruments. To circulate the sterilant and rinse water through the lumens and working channels of flexible and rigid endoscopes, specific connecting tubes have been designed to attach to the different styles of scopes.

This sterilization process requires filtered water of 50°C to dilute the sterilant to a 2% concentration, and the system is designed to empty the liquid concentrated sterilant via a drainage system that must be connected to the facility's waste management line. The final phase removes excess water by passing clean filtered air through the machine's chamber, including the tubing connected to the lumens and working channels of the scopes. This table top unit is equipped with a computerized printout of the cycle's temperatures, length of time, and verification of completion status. Another feature of this unit is its ability to run a diagnostic cycle before daily use to ensure the unit has full functionality. An internal sensor will stop the unit and abort the procedure if an error in the process is detected [5, 16].

Gas plasma

The newest method of sterilization is the hydrogen peroxide gas plasma sterilization system, which has been available in the USA since 1993. This low temperature system allows for sterilization of instruments, especially heat-sensitive or delicate instruments, in a rapid time range of less than 1 h to 75 min, depending on the model [15].

The process of this technology is based on gas plasmas which have been referred to as the fourth state of matter (i.e. liquids, solids, gases, and gas plasmas) [5]. There are five phases of this process: (1) vacuum phase, (2) injection phase, (3) diffusion phase, (4) plasma phase, and (5) vent phase. Terminal sterilization occurs after these five phases have been completed.

The positive aspects of this system are there are no toxic fumes: no plumbing connections, no aeration time, and no ventilation system is required. The compact, free-standing system requires an area of minimal square footage and a 208 V electrical source [16].

Flash sterilization

Flash sterilization is a high-temperature, high-moisture process used to sterilize unwrapped instruments rapidly for just-in-time use. This method is most useful when an instrument becomes contaminated during a procedure and there is no sterile replacement. Other reasons for using this method may include low-volume inventory of specialty instruments that are needed for back–to-back procedures, or a surgeon brings a specialty instrument required for a procedure that is not available in the healthcare facility. During the last several years, the use of flash sterilization in healthcare facilities has become more transparent due to an increase in evidence of surgical site infections (SSIs) in patients who had a flashed item used or implanted during their procedure [5]. Although this is an approved method of sterilization for immediate use of a cleaned instrument or medical device, excluding heat- and moisture-sensitive items, such as flexible endoscopes, it has become a controversial method of use.

The process of flash sterilization will not be effective if the instrument or device has not been appropriately cleaned, decontaminated, and rinsed according to the manufacturer's instructions. The cleaned item to be flashed is placed in an open mesh pan or a specially designed rigid container with a lid that allows for rapid penetration of steam [5]. Once the sterilization cycle has been completed the sterile item is transported in a covered fashion to the point of use. Ineffective cleaning and sterilization can result in an SSI, increased length of hospital stay, increased hospital costs, and liability.

Multiple issues need to be considered when approving this method of sterilization in a healthcare facility. A most crucial issue is the location where the instrument will be cleaned prior to sterilization. It is ideal for the instrument to be processed in a designated soiled utility room that is designed with negative pressure and 10 air exchanges per hour [17]. If there is no designated soiled utility room within the operating environment, then the instrument should be brought to the Central Sterile Processing Department for adequate processing. Location of the flash sterilizer will determine which pan or container method will be utilized, such as an open pan versus a steam-penetrating container with a lid. With the recognition of flash sterilization, healthcare facilities are placing flash sterilizers in close proximity to specific operating or procedure rooms to assist in aseptic transport to the sterile field. Personnel retrieving and transporting the sterilized device must don heat-sensitive gloves to avoid potential risk of a burn. Once the item is accepted into the sterile field, it must be allowed to cool before use to prevent a patient burn injury. If necessary, the flashed item should be placed in sterile saline to cool the temperature before use.

Depending on the type of sterilizer and the composition of the item to be flashed, specific guidelines from the Association for the Advancement of Medical Instrumentation (ANSI/AAMI) are recommended. The temperature, regardless of the sterilizer, is always 132° C (270° F). The recommended sterilization exposure time ranges from 3 to 10 min and depends on the type of sterilizer and the contents of the load. Drying times of 0–1 min are recommended for gravity-displaced sterilizers, depending on the item and the sterilizer manufacturers' instructions [5, 18].

Quality monitoring of the sterilizer's daily function and each cycle, along with documentation, is a vital part of this sterilization process. The types of monitoring for this process include physical, efficacy, chemical, and biologic rapid readout. Any breakdown in the process, such as incorrect temperature or a positive biologic indicator, must be reported immediately to management and the physician for further follow-up and corrective action.

Education of staff and documentation of competence of the procedure for flash sterilization is another important aspect of this process. Initial and annual training should be provided to all involved personnel, along with return demonstration by the staff to validate their competency in flash sterilization [18, 19].

To avoid overuse of flash sterilization, it is recommended to increase the inventory of high-volume items that are being flashed, to review the schedule the day before to anticipate the needs of instrumentation, after use to immediately sterilize surgeon or procedure specialty items to allow for sterile availability, and to receive implants in a timely manner to allow for a full sterilization process to take place prior to the procedure start time [19].

Other alternatives

HLD is the other alternative to sterilization in specific healthcare environments. HLD can be expected to kill all microorganisms, with the exception of a few bacterial spores when a high number is present [5, 14]. The steps of this process are similar to those of the sterilization process but do not include packaging or placement of an item in a sterilization container. The steps of this process are cleaning, rinsing, drying, and immersion in disinfectant solution, sterile water rinsing, drying, and immediate use or storage. The Food and Drug Administration (FDA)-approved agents for HLD are 2% glutaraldehyde, stabilized hydrogen peroxide, peracetic acid, and ortho-phthalaldehyde (OPA) [6]. The aldehyde agents are most commonly used for HLD. Glutaraldehyde has an alkaline pH and can be used for 24 weeks depending on the formula, but must be checked daily for potency [14]. Prior to use, staff must don PPE, including a full-face shield, impervious gown with sleeves, and nitril gloves. This chemical disinfectant must be prepared in a well-ventilated area with a low traffic pattern.

Before placement in the disinfectant solution, all items must be rinsed thoroughly to remove any residual detergent, and dried completely to prevent dilution of the disinfectant solution once an instrument is immersed in it [8]. Once an instrument is immersed, if it has lumens or working channels, the disinfectant solution must be flushed through-and-through three consecutive times for internal exposure. Exposure time ranges from 10 to 45 min with a solution temperature of 20–25°C [6]. After the recommended exposure time, the instrument is transferred to an adjacent basin filled with sterile water. The instrument is immersed in this and the external surfaces are wiped with a lint-free cloth. If the instrument has lumens or working channels, the sterile water must be flushed through-and-through three consecutive times to remove any residual disinfectant solution. The final step before use or storage is to thoroughly dry the instrument and, if it has lumens or working channels, air is forced through with a large sterile syringe. For use in a procedure, the instrument should be transferred to a sterile sheet or drape, covered in a sterile manner, and transported to the point of use. If a scope is to be stored, it is recommended that it be hung in a well-ventilated drying cabinet that supplies forced air in cycles. The scope is hung in a vertical position and connected to plastic tubing which enables the transport of forced air. This drying process prevents recontamination from residual fluid that may stay dormant in a scope and harbor bacteria growth, and further promotes thorough drying of the internal channels of an endoscope [6].

According to the AORN, the safest practice in the disinfection of endoscopes is to disinfect at the end of each day's use, again before the first use of the next day and again before each following use throughout the day [20].

Any healthcare facility that utilizes chemical disinfection must provide a safe environment for the set-up and protection of its personnel. The solution once activated and dispensed must be kept in a covered container with a tight-fitting lid, in a well-ventilated area. A free-standing or vented chemical fume hood is recommended for aldehyde solutions. With a free-standing fume hood, a carbon filter is installed and must be changed and disposed of according to the manufacturer's instructions [8]. Fume hoods are available in various sizes and designs to accommodate the facility's needs (Figure 1.4). A spill kit must be readily available in the event of spillage of the chemical solution.

OPA is a newer HLD that was approved by the FDA in 1999. It is less potent than glutaraldehyde, is not an irritant to the eyes and nasal passages, and has a shorter soak time of 12 min. Prior to 2004 this chemical was ideal for the HLD process for flexible cystoscopes, but due to reports of patients experiencing an anaphylaxis-like reaction after a cystoscopy procedure utilizing scopes that were processed with OPA, it is currently contraindicated for cystoscopes. OPA is the disinfectant

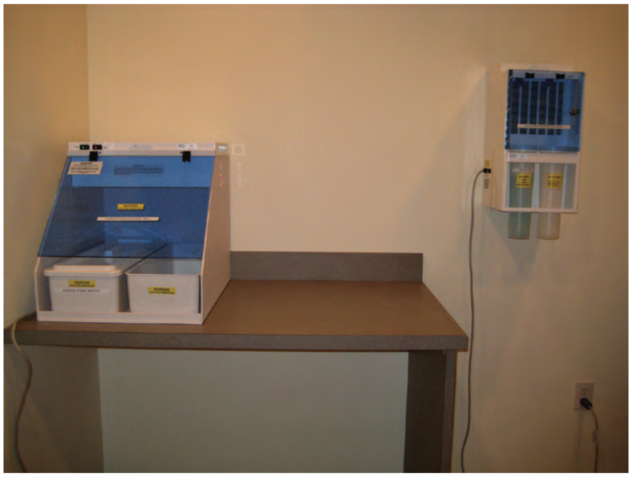


Figure 1.4 Table-top and wall-mounted fume hood for aldehyde solutions.

of choice for an ultrasound rectal probe used for guidance during prostate needle biopsy procedures. Prior to the immersion and soak time, an ultrasound probe must be cleaned, wiped or rinsed, and dried according to the manufacturer's guidelines.

Guidelines

Each healthcare facility will determine which method of sterilization is best for its practice. In a hospital setting, steam, gas plasma and peracetic acid are preferred for usage. Some ambulatory healthcare facilities have a steam autoclave, peracetic acid, and aldehydes for HDL as well.

Several organizations have developed guidelines for sterilization and disinfection of instruments and medical devices. AAMI developed recommended practices for steam sterilization in healthcare facilities. The Centers for Disease Control and Prevention (CDC) put together guidelines for disinfection and sterilization in healthcare facilities and guidelines to prevent surgical infections. The Association of Operating Room Nurses (AORN) has recommended practices for cleaning and caring for surgical instruments, sterilization, the use and care of endoscopes and HLD in the perioperative setting. The Joint Commission has standards to reduce the risk of infection associated with medical equipment, devices and supplies; this includes the processes of cleaning, disinfection, sterilization, and storage. In its survey of a healthcare facility, the aim was to document staff orientation, training, and competency in the mentioned processes. Other areas that it will focus on are quality monitoring and adherence to the manufacturer's instruction when processing medical devices or instruments. These organizations' recommendations serve as a resource for a facility's policy and procedure manuals and a guide to best practice.

Conclusions

The ultimate goals of instrument sterilization are to maintain a patient-safe environment, and provide quality patient care and positive surgical or procedural outcomes with no evidence of infections.

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CHAPTER 2

How to Protect Patients and Personnel from Radiation

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Introduction

General urology and specifically endourology are heavily reliant upon the use of radiographic procedures for both diagnostic and therapeutic purposes. Computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine, plain film radiography, ultrasound, and fluoroscopy are integral tools used for diagnosis, therapeutic planning, interventional treatments, and the follow-up of patients. Each has inherent advantages and disadvantages, and therefore the clinical agenda dictates particular imaging utilization. One common drawback for these technologies, with the exception of MRI and ultrasound, is the associated exposure to ionizing radiation. Due to the important role imaging plays in endourology, it is imperative that the creation of, doses administered, and risks associated with ionizing radiation are understood. Despite the essential nature of this knowledge, there is little or no formal education imparted to urologists or residents regarding radiation exposure.

Currently, the issue of radiation dosage is a national hot button topic. Errors in dose administration and the potential risks are national headlines. The Food and Drug Administration (FDA) has recently instituted an initiative to reduce radiation exposure associated with medical imaging below present levels (http://www.fda.gov). Manufacturers of new devices are required to comply with the Federal Food, Drug and Cosmetic Act's Electronic Product Radiation Control. Furthermore, devices already in use are legally required to be routinely tested to assure adequate function and safety, and these findings are to be logged with the FDA. Even with the regulatory guidelines, much of the burden of patient, employee, and physician protection falls upon the physician and administrator.

Typically, dose production for a CT, fluoroscope, or plain radiographic device does not vary for a given set of parameters; however, the settings chosen can be greatly altered to affect the output. Hence, the technician or physician performing the studies has direct control over patient and operator dosage. Therefore, it is up to the endourologist and technician to decide the balance between exposure and image quality. Additionally, the necessity of any imaging modality must be weighed. Consideration of each test's utility, the information to be gained, and how it will affect management are critically important. No radiographic study should be ordered without consideration of alternative imaging studies which may yield similar or superior information at lower radiation exposures.

A common theme in the practice of radiation protection is ALARA – *a*s *l*ow *a*s *r*easonably *a*chievable. The goal of this axiom is to minimize exposure to both patients and workers while obtaining the maximal benefit possible. The key methods of exposure limitation are time, distance, and shielding. Logically, minimization of imaging techniques associated with ionizing radiation is critical.

This chapter intends to briefly explain the rationale for concern over radiation exposure and potential risks. Additionally, we intend to describe the sources of X-ray production, estimates of exposure for various imaging techniques, and methods of protection and exposure minimization.

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Table 2.1 Typical doses and chest X-ray equivalents of common urologic imaging procedures.

Examination	Typical effective dose (mSv)	Number of chest X-ray equivalents
Chest PA	0.02	1
KUB	0.7	35
IVP	2.4	120
CT chest	8.8	400
CT abdomen or pelvis	10	500
PCNL	9	450
URS	2.5	125
SWL	1.6	80

KUB, kidney–ureter–bladder film; IVP, intravenous pyelogram; CT, computed tomography; PCNL, percutaneous nephrolithotomy; URS, ureteroscopy; SWL, shock-wave lithotripsy.

Background

Exposure to radiation is typically measured and reported in units of Gray (Gy). One Gray is directly proportional to joules of radiation absorbed per kilogram of tissue. However, this unit of measure is inadequate for estimates of risk because it does not take into consideration the relationship between absorption and tissue sensitivity. By using tissue sensitivity, the effective dose can be calculated and is expressed in Sieverts (Sv). Standard nomenclature describes the dose administered in milliSieverts (mSv) because the doses used for radiographic imaging are generally very low. Average medical imaging exposures can range from 0.7 mSv for a single plain abdominal film to upwards of 18 mSv for a CT scan, depending upon device settings and body habitus (Table 2.1). In comparison, naturally occurring background radiation exposure is 2–3 mSv annually.

Even with the relatively low associated doses, the concern over radiation exposure has grown recently due to the exponential rate at which medical imaging is used [1]. The risks of exposure can be categorized as deterministic or stochastic. Deterministic effects generally result in direct cell death from high doses directly administered to biologic tissue. Stochastic effects are those wherein the likelihood of an event increases with dose. Deterministic risks of excessive exposure range from entry site erythema, to cataracts, to desquamation and depilation. Diagnostic imaging is rarely associated with these side effects, but interventional procedures may exceed these thresholds [2]. The stochastic risks of greatest concern are increased potential of solid and hematologic malignancy. These risks are not inconsequential, particularly when considering accumulated lifelong exposures from the repeated studies which many patients undergo. There is a clear correlation between excessive exposure and the deterministic dermal and ocular effects. Debate, however, exists regarding the models used to calculate the stochastic side effects associated with radiation exposure.

Radiation production

Prior to understanding methods of protection, it is prudent to understand the principles of radiation physics and production. In this section we will briefly review the topic of radiation generation. A full detailed description is beyond the scope of this chapter but is readily available in radiation physics texts.

The basic components required for the generation of X-rays are two electrodes (an anode and cathode), a high voltage source, and an X-ray tube. Additionally, sources of radiation generation include a housing, which provides shielding and a collimator, which specifies the X-ray field. Within the shielded housing, electrons move from the cathode to the anode due to the potential difference created by the high-voltage source. As these electrons transfer, they gain kinetic energy in a ratio directly proportional to the potential difference between the cathode and anode [i.e. 20 kilovolt peak (kVp) = 20 kiloelectron volts (keV)]. The kinetic energy gained by the electrons as they cross from the cathode to the anode is then converted to other forms of energy upon impact with the anode. The vast majority of this kinetic energy is converted to heat. The remainder of the energy is converted into X-ray photons. This occurs when the electron comes close to the positively charged nucleus of the anode's material. Each X-ray photon is equal to the kinetic energy lost by these high-energy electrons.

The amount of radiation generated by individual electrons varies depending upon the proximity to the target material's nucleus. A direct impact transfers a large quantity of the kinetic energy and therefore generates maximum energy X-ray photons, while a more distant interaction generates weaker photons. The X-ray photons, or radiation, produced is termed bremsstrahlung, which translates to "braking radiation." The variability of distance from the nucleus therefore creates a spectrum of energy emitted from the X-ray tube, the bremsstrahlung spectrum. The mean energy of the photons across the spectrum is typically equal to one-third the total potential difference generated by the voltage.

The energy of photons is an important consideration because the higher the energy of the photon, the more shielding is required and the more readily the photon will penetrate tissue. Shielding levels for the X-ray housing are federally regulated to less than 100 mrad/h at 1 m to prevent excessive leakage rates while the tube is operating at maximum potential difference and current. The photons leave the tube through a small opening in the shielding and are directed towards the area of interest. Filters are then generally applied to these diagnostic X-ray beams. These filters attenuate the lower energy photons which do not have sufficient energy to reach the detector and therefore are not of clinical benefit. The electrons with energy high enough to penetrate through the filters are focused by the collimator through the tissue area of interest. Typically, the collimators further restrict exposure to the patient and the operator by eliminating radiation exposure outside the area of interest.

The quality of the image obtained is significantly dependent on the energy level and quantity of the electrons reaching the detector. The X-ray photons need to be of high enough energy to penetrate through the tissue but low enough to limit "over-exposure" of the detector. Therefore, the most controllable aspects of diagnostic imaging equipment are: the potential difference (kVp), which determines the amount of energy in X-ray photons; the current (mA), which determines the number of electrons that create photons for a given time period; and exposure time, which combines with the current to determine the total quantity of X-rays produced (mAs). Because exposure is proportional to the square of kVp and linearly related to mAs, it is optimal to increase kVp prior to increasing mAs to increase an image's exposure. Conversely, if an initial image is "over-exposed," reducing mAs will more greatly reduce radiation dosages.

Understanding the basic principles and mechanisms of X-ray generation provides a foundation for the understanding of radiation protection. Proper equipment maintenance and inspection of shielding and filters are requisite parameters for operators of imaging equipment. An understanding of the electrical parameters and their effects on X-ray generation can lead to optimization of the image quality while minimizing dose to patients and operators. Finally, the use of collimation to limit the exposure field to precisely the tissue area of interest can greatly restrict unnecessary exposure.

Risks of excessive radiation exposure

As mentioned earlier, the risks of excessive radiation can be divided into two general categories: deterministic effects and stochastic effects. Deterministic effects are due to radiation-induced cell death and occur after a relatively large radiation dose. These effects include cataracts and skin injury. The radiation dose thresholds for developing erythema and more severe skin injuries are relatively well-established. Doses of 300–600 rad can cause temporary depilation and erythema, while 1500–2000 rad can cause desquamation, dermal necrosis, and ulceration [2]. The minimum dose that has been shown to produce a progressive cataract is 200 rad. Normally, in modern diagnostic and interventional imaging, the doses delivered are well below these threshold levels.

Stochastic effects occur by chance without threshold levels. The probability of an effect is associated with dose, but the severity is independent of dose. The main stochastic risk of increased radiation exposure is the development of hematologic or solid malignancy. The level of radiation exposure that is dangerous remains controversial with two diverging theories: linear no-threshold model (LNT) and hormesis theory. In the LNT model, radiation exposure is considered additive over time and linearly extrapolated to determine risk. The risk of developing malignancy is directly related to the cumulative amount of radiation exposure. Alternatively, the hormesis theory suggests that at low doses, radiation exposure is not damaging, but actually may serve a protective role. This model hypothesizes that below a certain threshold level, ionizing radiation will not contribute to an increased risk of malignancy [3].

The more widely accepted and more prudent theory is the LNT model. The estimated risk of malignancy, according to the LNT model, is based primarily on data from approximately 35 000 atomic bomb survivors and 400 000 nuclear industry workers. These calculations estimate an excess relative risk of 0.32–3.15/mSv depending upon the type of malignancy for nuclear industry workers and atomic bomb survivors [4]. Furthermore, epidemiologic analysis from these data shows a risk of radiation induced fatal cancer of 5%/Sv for the general population [5]. More specifically, certain risk models take into account the type of radiation, dose, and age and sex of patients exposed. For example, a 25-year-old man exposed to a one-time dose of 10 mSv of ionizing radiation would have a 0.05% chance of developing a lethal cancer, compared to a 0.02% chance for a 45-year-old man under the same circumstances. The baseline risk of developing malignancy from all causes is approximately 20% over a lifetime. Thus, for the 25-year-old in this example, his overall risk would increase to 20.05%. This increase in risk, while low, becomes more significant with younger age of exposure and exposure accumulation over the patient's lifetime. The use of CT scans, which currently represent the most significant contribution to a patient's medical radiation exposure, has risen three-fold since 1993, up to 70 million scans a year. Despite low individual risks, the increasing exposure to the population is projected to create a relatively large number of cancers. In fact, Brenner and Hall suggest that nearly 0.4% of all current cancers in the USA may be attributable to CT usage [1]. Additionally, in a recent report, de Gonzales *et al*. estimated that 29 000 future cancers could be attributable to ionizing radiation produced by CT scans in the USA in 2007 [6].

Using this model, the International Commission on Radiological Protection (ICRP) has set forth recommendations limiting *occupational* exposure to 50 mSv in any given year or 20 mSv/year over a 5-year period [5]. National and international organizations, including the US National Council on Radiological Protection and Measurements, the US National Academy of Sciences Biological Effects of Ionizing Radiation, and the ICRP, among others, unanimously agree that for radiation doses less than 100 mSv, the LNT is the most appropriate risk model [7].

It must be emphasized that these guidelines are for occupational exposure and do not provide any more than a framework for the practicing physician. There typically is a significant benefit gained from the exposure associated with medical imaging. Proper diagnosis can lead to proper management and optimal medical care.

Sources of ionizing radiation encountered in urology

Diagnostic imaging

It is well accepted that the utilization of medical imaging is inseparable from the evaluation of most patients and complaints. The ability to visualize anatomic and functional complaints greatly enhances the clinician's ability to care for individual patients. Unfortunately, many of the most commonly utilized modalities incorporate ionizing radiation to attain the necessary images. Plain film radiography, CT, and nuclear medicine studies all expose patients to various doses of radiation. Only ultrasound and MRI avoid such exposure, but these too have their own limitations.

Traditionally, plain radiography with a kidney–ureter–bladder (KUB) film has been the initial imaging modality for many patients with urologic complaints. In patients with nephrolithiasis, the majority of stones contain calcium and therefore will be readily apparent on plain radiograph. Certain stone compositions, most notably uric acid, will not appear on KUB. The identification of stones can be further complicated by overlying bowel gas, extraluminal calcifications, and patient body habitus. The advantages of KUB are low cost, worldwide availability, and a low effective radiation dose of 0.2–0.7 mSv. The sensitivity and specificity for detecting urinary stones is reportedly 59% and 71%, respectively [8].

Intravenous pyelogram (IVP) has benefits similar to KUB, and offers added information regarding anatomic detail and function. The use of contrast allows for the identification of key structures. As contrast fills the collecting system and ureter, the presence and location of urinary tract obstruction can be evaluated. Additionally, renal and urothelial masses and urolithiasis can be evaluated by IVP with special attention paid to the contour of the collecting system and the presence or absence of filling defects. IVP is associated with improved sensitivity and specificity to detect stones over KUB alone, reported as 64% and 92%, respectively [9]. The estimated effective radiation dose is 0.7–3.7 mSv, based on the number of images obtained [10]. The main drawbacks of IVP are a relatively long procedural length and the need for intravenous contrast, with its associated risk of contrast-induced nephropathy and allergic reaction.

CT is widely used in the diagnosis and follow-up of many urologic conditions. It is currently the ideal test for assessment of renal masses and renal cystic disease. CT urogram has largely replaced IVP for assessment of ureteral abnormalities. Additionally, CT is routinely employed in the metastatic work-up of virtually all urologic malignancies. Unenhanced CT is the gold standard for the diagnosis of urinary stones with sensitivity and specificity of near 100% [11]. Additionally, in the evaluation of a patient with acute flank pain where a ureteral stone is suspected, CT can suggest alternative diagnoses. In a retrospective review of 1000 patients evaluated by CT, Katz *et al*. found 101 exams revealing alternative or supplementary diagnoses [12]. As with all diagnostic studies, CT has its pros and cons. CT provides excellent anatomic detail, but is associated with a higher relative cost, less widespread availability, and a high effective radiation dose of 4.5–18 mSv [10].

For patients with nephrolithiasis, radiographic imaging is inseparable from accurate diagnosis, treatment, and follow-up. To quantify patient exposure during a single stone episode, John *et al*. performed a retrospective analysis in the UK, where CT is not routinely used. Of the 60 patients included in the study, only 14 had CT scans. The patients received a median effective dose of 5.3 mSv (1.18–37.66 mSv). Notably, those patients who underwent a CT scan received significantly higher exposure levels than those who did not (14.46 mSv vs. 4.25 mSv) [13]. More recently, we reported the radiation exposure associated with an acute stone episode and 1 year of follow-up at two academic centers in the USA and found the median effective radiation dose to be 29.7 mSv, with 22 of 108 patients (20%) receiving over 50 mSv. In the group that received over 50 mSv of radiation exposure, the average number of CT scans was 3.5 [14]. One limitation of the study was that it did not include radiation exposure from interventional imaging, which may be a significant contributor to a patient's overall exposure profile.

Interventional imaging

Fluoroscopy is the main interventional imaging modality used by urologists. It allows for realtime imaging in many urologic procedures, including percutaneous nephrolithotomy (PCNL), retrograde pyelography, ureteroscopy, and shock-wave lithotripsy (SWL). In a recent study, the mean effective dose for PCNL was 9.2 mSv (0.82–26.0 mSv) [15]. In an ongoing study at our institution, we found the mean effective dose during PCNL to be 9.09 mSv (0.46–51.6 mSv), with body mass index (BMI), stone burden, nonbranched stone configuration, and number of percutaneous access tracts to be associated with increased radiation dose [16]. The mean effective dose for ureteroscopy has been previously reported as 2.5 mSv, with exposure being higher when flexible endoscopes were used compared to semirigid devices; and highest when both devices were utilized in the same setting. The authors proposed that this effect is likely related to the increased complexity of the case. They additionally noted that radiation exposure was higher in therapeutic procedures compared to diagnostic procedures [17]. In a recent study of 50 SWL cases, the mean effective dose to the patient was 1.63 mSv, with a mean fluoroscopy time of 204 s [18]. The factors associated with increased radiation exposure during SWL were increasing stone burden, patient weight, and ureteral (as opposed to renal) stone location [19].

Dose reduction strategies

There are numerous methods to reduce radiation exposure to patients, beginning with the elimination of unnecessary studies, proper radiation safety education, and the optimization of modalities that do not use ionizing radiation, such as ultrasound and MRI. Unnecessary radiographic imaging has plagued modern medicine. One study in the pediatric literature suggests that up to one-third of all CT exams could be eliminated or replaced by alternative approaches [20]. Therefore, judicious use of imaging alone could significantly reduce dose to patients. Additionally, success in reducing radiation dose has been shown with the implementation of a "radiation awareness program," where focus was placed on taking fewer "snapshots" during SWL [21]. Also, after implementing a radiation safety education initiative, one group noted significant decreases in dose area product and fluoroscopy time for several of their most common pediatric procedures [22]. By optimizing usage of imaging procedures that do not use ionizing radiation, such as ultrasound and MRI, urologists can greatly reduce overall dose to patients.

Ultrasound has recently gained acceptance as a modality for obtaining access to the collecting system during PCNL. When it is utilized for access purposes, there is a significantly reduced fluoroscopy time. The use of ultrasound was, however, associated with a longer overall procedural time [23]. Additionally, ultrasound can be combined with other imaging modalities, such as KUB, and together used in place of CT. Catalano *et al*. compared CT to the combination of KUB and ultrasound for the evaluation of renal colic and concluded that, though CT showed better sensitivity (93% vs 77%), specificity was comparable (96% vs 93%). Of the 48 patients who underwent KUB and ultrasound, six (12.5%) had false-negative results. However, all six patients with false-negative results had uncomplicated courses with spontaneous stone passage [24]. Therefore, the combination of KUB and ultrasound has good practical application and is a viable alternative when CT is contraindicated, unavailable, or otherwise less preferred.

MRI or magnetic resonance urography (MRU) is a technique that produces no ionizing radiation and can be used to evaluate the genitourinary system. MRI previously had a significant role in chronic kidney disease patients where iodinated contrast with a CT or IVP was contraindicated, but it too is now contraindicated in patients with renal impairment secondary to gadolinium's association with nephrogenic systemic fibrosis. MRI provides excellent anatomic detail and can be used without concern in pregnant patients. However, it is a poor exam for the evaluation of stones, as their appearance is that of a signal void, similar to blood clots and tumors. For ureteral stones, multiple studies have demonstrated that MRU can rapidly and accurately determine the level and degree of ureteric obstruction, as well as the presence of perinephric fluid [25, 26]. A study combining CT and MRU showed a detection sensitivity of 98% and that a marked reduction in effective radiation dose to 0.52 mSv can be obtained. This report utilized MRU to identify the level of obstruction and a subsequent targeted CT to characterize the cause of obstruction [25]. Though this combination shows high sensitivity with minimal radiation exposure, it may have minimal clinical applicability because it is time-consuming, expensive, and MRU is not widely available.

Dose reduction strategies in CT

In the current urologic and medical landscape in general, the majority of patient radiation exposure is derived from diagnostic and follow-up imaging procedures via CT scanning. As CT is widely regarded as the optimal diagnostic modality for the evaluation of patients with stone disease and indicated for the follow-up of many urologic diseases, efforts have moved toward reducing the radiation dose associated with these studies. Strategies to reduce radiation exposure can be broadly classified into two groups. First are strategies associated with the basic design of scanners and their components, including the efficiency of detectors and X-ray tube characteristics. Second, there are a number of technical parameters that can be modified by the radiologist or technician to reduce radiation exposure, including pitch, slice thickness, and tube current.

Pitch, the speed at which the table moves through the scanner gantry, can be adjusted to decrease radiation dose, whereas increasing pitch will decrease radiation dose. In a single-slice helical CT, moving from the standard pitch of 1 to 1.5 causes a 33% reduction in effective dose, while still maintaining adequate image quality [27]. However, this correlation between pitch and dose does not hold true in all multislice scanners. One study showed no difference in measured radiation dose through all pitch selections, because of an automatically proportionate increase in tube current applied by the multislice scanner [28].

Slice thickness is another parameter that can be adjusted to potentially reduce radiation exposure. In general, thinner slices will provide more information, but also expose the patient to a higher level of radiation. The goal, therefore, is to optimize slice thickness to find clinically relevant pathology without exposing the patient to excessive radiation. For the diagnosis of nephrolithiasis, one study showed 70% more stones detected with 0.5-mm slices compared to 5-mm slices, but at the cost of markedly increased radiation exposure [29]. The current consensus is that 2.5-mm slices are adequate for the detection of most clinically relevant stones. Also, by increasing the number of detectors on a multidetector CT scanner, the changes between slice thickness have less effect on radiation dose. For example, with a four-detector device, moving from 1-mm slices to 2.5-mm slices would decrease the effective radiation dose by 30%. The same change in a 16-detector device would lower the dose by 10%. A 64-detector device would show no change in radiation dose when moving between different slice thicknesses [30]. This can, however, be misleading, because as a general rule, increasing the number of detectors will increase radiation dose due to thinner slice collimation [31].

The most significant way to reduce effective radiation dose is by reducing tube current. Many CT scanners utilize dose modulation software which adjusts the dose based on patient body habitus, and the density of tissues penetrated by radiation. The software uses the scout image to make adjustments in radiation output, decreasing radiation dose in thinner, less dense parts of the body. Reduction in tube current will, however, produce images with more "noise." For certain imaging purposes, such as the detection of urinary stones, which are high-contrast objects, a higher level of "noise" is acceptable without limiting diagnostic capabilities.

Low-dose CT scanning has been developed that accepts a relatively high level of "noise" in return for a marked reduction in radiation dose. Multiple studies have shown that low-dose CT can produce equivalent sensitivity and specificity in detecting nephrolithiasis when compared to standard CT. Ciaschini *et al*. showed comparable sensitivities between standard CT and simulated CT reconstructions at 50% and 75% reduction from the original dose for stones greater than 3 mm [32]. Another study showed similar detection ability with low-dose CT for stones greater than 2 mm, with a reduction in radiation dose of 81%, to a mean of 1.4 mSv for men and 1.97 mSv for women [11]. Also, Polletti *et al*. studied 125 patients with renal colic who were evaluated with both standard and low-dose CT scans, where men received an estimated 9.6 ± 1.2 mSv and 1.6 ± 0.2 mSv, and women 12.6 ± 1.8 mSv and 2.1 ± 0.3 mSv, respectively. For patients with a BMI of less than 30 kg/m^2, the sensitivity was 95% and specificity was 97% for detecting ureteral calculi of all sizes. In patients with a BMI of 30 kg/m^2 or greater, the sensitivity of low-dose CT to identify ureteral stones was 50%. Of note, there were only 13 patients with a BMI of 30 kg/m^2 or greater, and of the stones that were not identified, only one was greater than 3 mm [33]. Though the number of obese patients in this study is small, these results are consistent with other studies, highlighting the notion that low-dose CT may be limited in the obese population and may fail to identify stones smaller than 2–3 mm.

In contrast, Mulkens *et al*. demonstrated comparable sensitivity, specificity, and accuracy between standard and low-dose CT across all BMI ranges with the use a 16-detector CT and tube current modulation. The standard CT had a relatively low mean effective dose of 2.89 mSv, which was decreased 51% further to a mean effective dose of 1.41 mSv, with low-dose parameters applied. The tube current modulation software caused the dose range to be quite variable, 0.73–2.7 mSv in the low dose group, with a direct correlation noted between effective dose and BMI (Spearman coefficient 0.86–0.88) [34]. The results of this study show that with modern equipment, obese patients require a higher, but overall relatively low, radiation dose for accurate detection of urinary stones. These studies utilizing low-dose CT appear to show exciting promise. Extreme dose reduction is only appropriate for nonobese patients and even then, the ability to detect very small stones may be limited. However, it appears that moderate dose reduction can be achieved with adequate detection ability even in obese patients.

While much of the dose reduction work focuses on patients with nephrolithiasis, patients with malignant diagnoses undergoing surveillance protocols or follow-up imaging would also likely benefit from minimization of exposure. The optimal parameters for patients in these situations have yet to be determined but is a potential future research direction.

Dose reduction strategies with fluoroscopy

In 1995, the FDA began regulating the maximum output of fluoroscopy units with specific levels set for normal (10 rad/min) and boost (20 rad/min) modes. These outputs are achieved by the maximum potential energy (120 kVp) and current (2 mA) settings. Therefore, since most fluoroscopy units generate similar radiation profiles, the radiation exposure to patients and operating room personnel is dependent on the operator and type of procedure.

Fluoroscopy exposure during PCNL is associated with a mean effective radiation dose to patients of approximately 9 mSv, approximately the equivalent of a standard abdominal CT scan. The range of exposure from one study was broad, with several patients receiving greater than 50 mSv [16]. Therefore, fluoroscopy during interventional procedures can be an important contributor to a patient's overall radiation exposure profile. A number of improvements have been made by manufacturers of fluoroscopic imaging equipment in recent years with the goal of producing the highest quality image with the lowest possible radiation dose. These improvements include the use of low attenuation materials, such as carbon fiber, in table tops and cassettes, improved energy spectra produced by high-frequency generators, and additional filters to reduce entrance skin dose. Equipment design and component position can influence scatter and leakage radiation. With the X-ray tube located under the fluoroscopy table and the image intensifier above the table, most scatter and leakage radiation is shielded by the table itself and will not cause significant occupational exposure. Also, features such as last image hold, pulsed fluoroscopy, and digital imaging have contributed significantly to lowering patient exposure. Last image hold enables the last image produced to be maintained on the monitor as opposed to a blank screen, limiting unnecessary re-exposure. With the advent of digital imaging, pulsed fluoroscopy is possible. In continuous mode, pulsed fluoroscopy, refreshes the image at a rate of 30 frames/s. This can result in an 80% reduction in radiation dose over traditional, continuous imaging without impacting image quality. Additionally, by adjusting the device to a pulse rate of 15 frames/s, radiation dose can be further reduced [35]. These features are inherent to the device and many are automatically selected.

There are also several factors that are under the control of the operator and can be further maximized to limit radiation exposure, highlighting the importance of a well-trained and experienced fluoroscopist. They include acquiring as few images as possible, precisely collimating the beam to the region of interest, limiting the use of magnification, and strict adherence to the ALARA principles.

Protection from ionizing radiation

The basis of the ALARA concept is the avoidance of unnecessary radiation. Because of the valuable information gathered from radiographic studies, a key concept of the ALARA principle is that the avoidance of exposure must be reasonable in that it does not hinder the performance of the study, is not high cost, is not overly time-consuming, and offers a significant reduction in exposure. The basic principles of ALARA are time, distance, and shielding.

Time

The most efficient and effective way to limit radiation exposure to patients and healthcare personnel is to limit the time of the study. When using fluoroscopy, it is important to capture images only when necessary. Many authors have admitted that it is easy to let the device run continuously, even for the smallest step in a procedure. Also, it is best to have the surgeon operate the on–off function of the device by using a foot pedal. If this is not possible, it is imperative to have a well-trained and experienced fluoroscopist and effective communication between the fluoroscopist and the surgeon. Reducing the amount of time spent in the vicinity of the device also decreases the amount of radiation exposure for those performing and assisting in the procedure. Those individuals who are not actively tending to the patient should not spend time near the fluoroscopy equipment while it is in use. Several advances that have been discussed previously – last image hold, digital imaging, and pulsed fluoroscopy – are all ways in which fluoroscopy time can be reduced. In one study, conversion from a film screen to digital fluoroscopy with last image hold showed a radiation dose reduction of 70% [36].

Distance

X-rays act like visible light and other electromagnetic waves in that they spread out in three-dimensional space as distance increases. As a result, the area geometrically increases as a function of distance from the source and radiation exposure becomes inversely proportional to the square of the distance – the law of the inverse square. By doubling the distance, the radiation exposure is decreased by a factor of four. By tripling the distance, the exposure is deceased by a factor of nine. At a distance of 12 feet from the source, the radiation dose is reduced to background levels. Distance represents one of the easiest ways to limit exposure to operating room personnel, and therefore, those individuals who are playing noncritical roles should separate themselves from the procedure.

Shielding

Once time and distance have been optimized, the next level of protection is shielding, in particular for those persons who are required to be within the region of exposure. Shields are usually made of heavy metals, most commonly lead, that can effectively attenuate radiation. Shields can be part of personal protection in the form of lead aprons, thyroid shields, eyeglasses, and gloves, or incorporated into room design, such as a ceiling-mounted shield. Most aprons are 0.5-mm equivalent lead thickness and attenuate radiation by 96.5–99.5% for the potential energy range most encountered during fluoroscopy (70–100 kVp). Movable transparent lead shields and drapes can also be used to further reduce exposure to individuals operating close to the radiation source. One group designed a urologic surgery radiation drape to be used for endourologic procedures that reduced radiation dose to the urologist by 70-fold over apron and thyroid shielding, but this drape was not widely accepted as many thought it was too cumbersome [37]. Overall, shielding can effectively be used as the last line of defense, with only very minimal impact on the tasks being performed.

Conclusions

Urologists deliver and prescribe a great deal of ionizing radiation to their patients. This exposure comes with meaningful, albeit small, risk. Great strides have been made on numerous fronts to reduce radiation exposure. However, additional work needs to be done, as certain patients are still being exposed to excessively high radiation doses. The urologist must understand radiation safety in order to protect the patient, themselves, and the operating team from potential radiation injury. The importance of the ALARA concept, minimizing time, maximizing distance, and the appropriate use of shielding, cannot be overstated. Ultimately, there are several important ways to reduce patient and provider radiation exposure. First, we must be certain that proper justification exists for an imaging study or procedure. Second, we must consider alternative means of imaging, when clinically appropriate. Last, we must work in conjunction with radiologists to balance radiographic image quality with radiation dose, especially in stone patients where the use of low-dose CT appears promising. Communication between the ordering physician and radiologist is critical to determine the most ideal imaging parameters needed to answer a particular question, ensuring that the lowest possible radiation dose is administered. It is the responsibility of all physicians, including urologists, to implement ways to reduce radiation dose without compromising patient care.

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CHAPTER 3

Video Imaging and Documentation

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Introduction

Innovations and improvements in video imaging technology have paved the way for significant advances in endourology and minimally invasive urologic surgery. Recent advances in technology have turned what once appeared to be science fiction into reality. Virtual reality simulators, three-dimensional video imaging, telementoring, and video image overlay are all being incorporated into current surgical practices. These technologies are not only facilitating the performance of complex surgical procedures, but are also allowing wider dissemination of the skills needed to perform these procedures. As these technologies continue to develop, their applications in minimally invasive endourologic practice will only grow.

This chapter will review the current state of the art of video imaging and documentation systems within endourology. Technologic advances and their application in current endourologic practice will be discussed. It is anticipated that this information will not only help the reader to enhance their video imaging practices today, but also prepare them for tomorrow's tremendous innovations in advanced imaging modalities.

Digital imaging

A number of major improvements have greatly enhanced videoendoscopic surgery [1–3]: the development of the charged coupled device (CCD) chip camera and the introduction of digital video imaging. Once an optical image is focused on the CCD chip, there is a conversion of the optical (light) image to an electronic signal [4]. This electronic information, which includes both color and light (luminance), can be scanned by a video monitor to produce an image on the screen.

Standard National Television Systems Committee (NTSC) video signals utilize a limited "bandwidth," which includes both the color and luminance information in a single or "composite" signal. Problems with this format include "signal noise," which is caused by the camera having to first process color and luminance information separately and then combine the two pieces of information to create a video signal. This video noise or "cross talk" may be the cause of decreased resolution, grainy images, and loss of information around the edges of the video image. Moreover, this video noise will increase as additional copies of the video tape are produced.

With the advent of digital imaging, two newer video formats have been introduced [5]. The first format allows the color and luminance information to be carried as two separate signals. This "component" video signal is called Y/C, with Y standing for luminance or light brightness and C referring to color. Also known as SuperVHS (or S-VHS), this component signal contains less cross talk and therefore appears cleaner and sharper than images generated by composite signals. The video signal in a Y/C format is carried by a single cable, as with the NTSC format, although the color and luminance information are still separated.

The final digital video format is known as RGB (red–green–blue). This RGB format is also a component signal, yet it is distinct from the Y/C format in that the video information (color and luminance) is separated into four signals. These include a red, green, and blue

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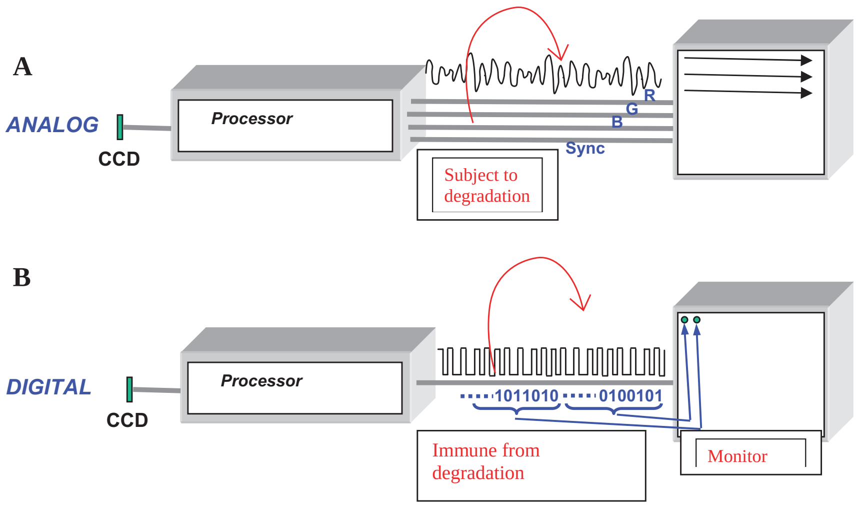

Figure 3.1 (A) Representation of analog video imaging in which video signals remain as voltage waveforms. (B) In contrast, digital video systems convert the analog video information to a digital format, which must then be converted back to analog information before it is viewed on the video monitor. Conversion to a digital signal gives the digital video image immunity to noise build up or image quality degradation.

signal as well as a timing signal. Each individual signal carries its own luminance information. Separation of the video signals is performed electronically in the camera head. The RGB format requires less electronic processing than do the NTSC or Y/C formats since the color and luminance information are separate from the start. Therefore, the RGB image quality is greatly enhanced as compared to the other two formats. Also, in contrast to the single cable NTSC and Y/C formats, the RGB video signal is carried by four separate cables (red–green–blue and sync). While most video monitors will accept standard NTSC video formats, a special (and more expensive) monitor is required to accept Y/C and RGB formats. The increased price, however, will result in a far superior image to standard NTSC formats.

In standard analog video processing (NTSC format), images or signals remain as voltages (Figure 3.1A). Small errors in recording and reproducing these voltages are inevitable and the errors accumulate with each generation of the video image. Hence, multiple copies of an analog image will reveal a decrease in the quality of the video pictures. In contrast, a digital convertor changes all video signals into precise numbers (e.g. 0 or 1) in the digital video formats (Y/C and RGB) (Figure 3.1B). Conversion to a digital signal gives the video image immunity to noise build up or image quality degradation. Moreover, image processing can be performed to enhance (and in some cases, alter) the digital video images. Once the video information has been digitized, it can be merged with other formats (text, data, audio, etc.), transmitted or copied, with no loss of information.

Standard video systems

The technical advantages created by video monitoring include binocular vision and magnification of the monitor images. Magnification may be as great as 20 times, depending on the initial optics system used. This enlarged image permits better inspection of detail and allows the operator, by virtue of the enlarged image size, to perform the procedure off the monitor rather than looking directly through the endoscope [6]. This approach significantly decreases operator strain because the surgeon no longer needs to conform their body to the angle of the viewing lens. Instead, the urologist can simply attach a video camera to the scope and manipulate the endoscope while standing comfortably and observing the video monitor [3]. Moreover, the upright position assumed by the urologist decreases the likelihood of coming into contact with potentially infected body fluids.

Video cameras

All video systems are currently composed of a CCD solid-state chip camera, a video processor with or without a video recorder, and various video accessories. All of the chip cameras are fully immersible and shielded from electrical interference that may be created by cutting or coagulating currents during endoscopic procedures [7]. The CCD chip high-resolution camera should have an automatic white balance feature which allows one-touch color balance, assuring true to life color reproduction. Additional features of the CCD

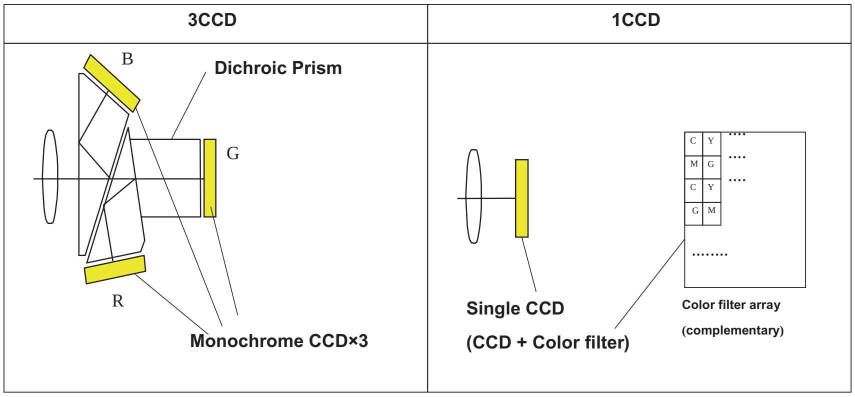

Figure 3.2 Schematic representation of three- and one-chip charged coupled device (CCD) designs. Red, green, and blue sent to three separate CCDs by a prism.

camera may include a high gain option which will boost the video signal to provide an exceptionally clear image, as well as a color bar option that allows the surgical team to adjust the monitors to represent accurate camera color prior to beginning the case.

Advances in CCD camera technology have significantly downsized current endoscopic video cameras, thereby allowing easier movement of the endoscope with the attached camera. With the recent significant improvements in CCD technology, tube cameras are no longer utilized due to their large size. When recording an actual endoscopic procedure, the camera may provide a remote control switch for a video recorder, allowing instant fingertip pausing of the recording device during documentation. Additionally, the camera head should be designed to prevent fogging between the coupling device and the camera head. All manufacturers can supply camera head adapters for other endoscopic systems. Finally, the entire camera head cable and edge card can be completely cold soakable in disinfectant solutions for easy sterilization between endoscopic cases.

As noted previously, CCD chip cameras have supplanted the tube cameras which were the first video systems on the market. A significant improvement in CCD camera technology has been the development of the three-chip camera that contains three individual CCD chips for the primary colors – red, green, and blue (RGB) (Figure 3.2). In addition to composite S-VHS and component signals, the three-chip cameras also provide an "uncoded" RGB signal. Color separation is achieved using a prism system overlying the chips [8]. This three-chip camera design provides improved color fidelity and enhanced image resolution. Moreover, three-chip cameras produce less "noise" due to the pure RGB signals [9, 10]. A digital converter captures each voltage signal as an image and translates the voltage values into discrete numbers, either as 0 or 1. The encoded numbers for each image element, or pixel, include information on color, light intensity, and contrast. These variables can then be modified using image-processing software within the camera [11].

In theory, three-chip cameras produce better quality images than single-chip cameras. Despite the apparent advantages of three-chip cameras, some clinical comparisons have favored one-chip systems. Using normal video monitors, previous studies have implied that the resolution between the two cameras did not alter the visual perception of an image. Studies have found that digital contrast enhancement is a more important feature for endoscopic imaging than the number of camera chips. Three-chip cameras appear to have no advantage over well-designed single chip systems [8, 12, 13] However, this apparent limitation may change with the introduction of high-resolution digital monitors and high-definition television (HDTV), as the amount of image information and the degree of perception are increased with these digital imaging modalities [14; see below].

Many of the CCD chip cameras (both single- and three-chip) contain electronic shuttering mechanisms that automatically adjust exposure time from 1/60 to 1/16 000 of a second. The advantage of such a sophisticated detection circuit is that the camera can react to varying light conditions almost instantaneously, reducing the flaring, "washout," and "blackout" which were noted with early video systems. Moreover, electronic shuttering mechanisms within the camera usually work more quickly than automatic light sources.

Videoendoscopes

A major advance in the endoscopic systems has been the development of the digital videoendoscope. Miniaturization of chip technology now allows a CCD chip to be incorporated at the distal end of the

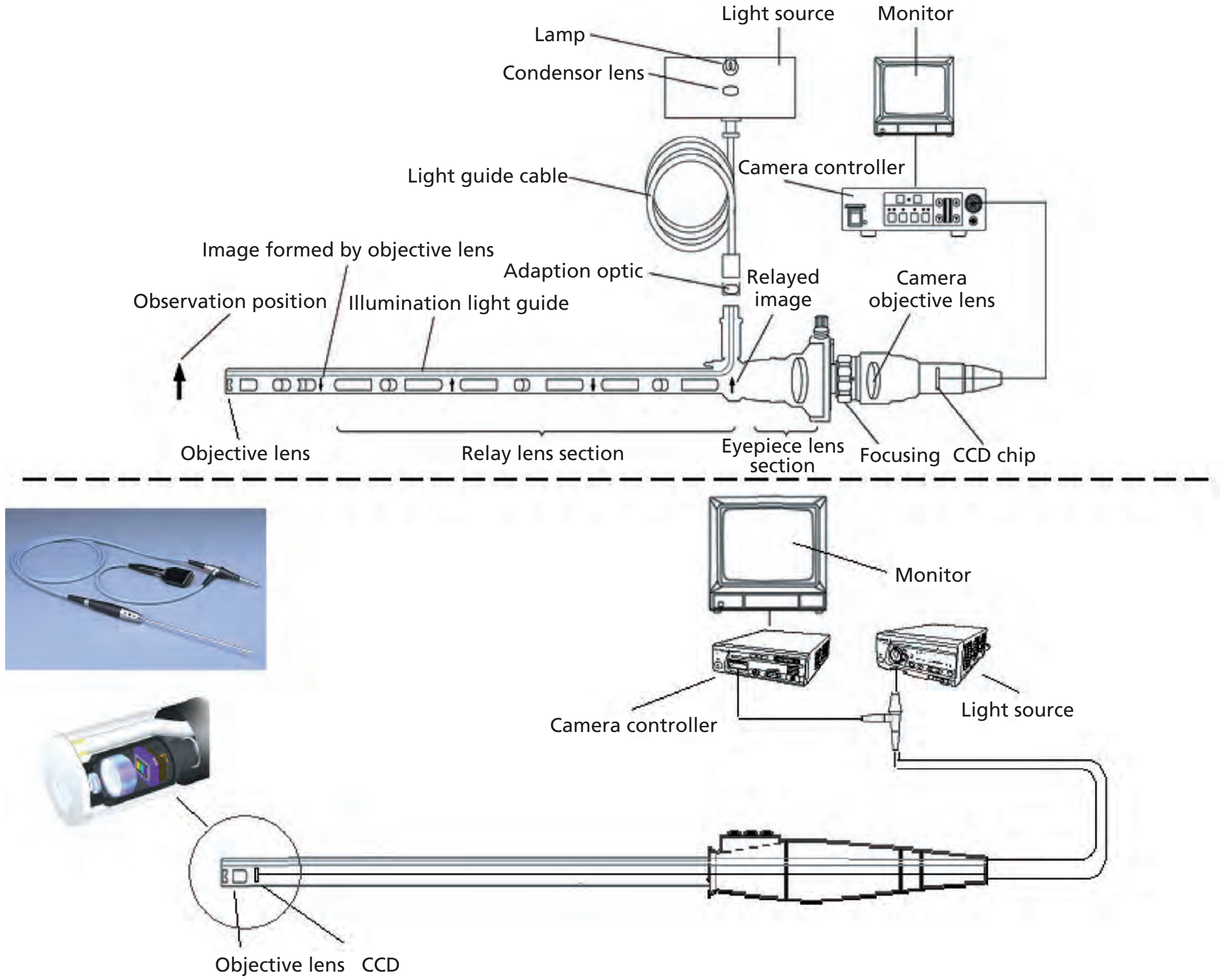
Light source
Monitor
Lamp
Condensor lens
Light guide cable
Camera controller
Image formed by objective lens
Adaption optic
Relayed image
Camera objective lens
Observation position
Illumination light guide
Objective lens
Relay lens section
Eyepiece lens section
Focusing
CCD chip
Monitor
Light source
Camera controller
Objective lens
CCD

Figure 3.3 Traditional technology (top) compared with electronic transmission videoendoscopes (bottom). CCD, charged coupled device (photograph reproduced courtesy of Olympus ACMI Business Group, a division of Gyrus ACMI, LP, Southborough, MA, USA).

endoscope (Figure 3.3). Instead of relaying optical images from the objective lens at the distal end of the scope to a camera attached to the eyepiece, the image is immediately captured by the CCD chip, digitized, and converted into electrical signals for transmission. This endoscope design has fewer interfaces, allowing the digital information to be directly transmitted to an image display unit with minimal image loss, interference, and distortion [15, 16]. The creation of true videoendoscopes especially benefits the flexible ureteroscope and cystoscope. As internal optics are not required in the long and flexible shafts of these instruments, durable deflection mechanisms can be utilized to improve the durability of flexible endoscopes [17, 18]. With no need to attach a camera head to the eyepiece of the scope, the videoscope cable can be secured to the light cord for attachment to the video system, providing a lighter and more convenient set-up. This technology has been incorporated into larger, rigid endoscopes (laparoscopes), as well as rigid and flexible cystoscopes and ureteroscopes [19–21]. This innovation is due to recent technologic advances which have allowed miniaturization of CCD chips. Such an integrated digital videoendoscope can be expected to replace many endourologic endoscopes in the near future.

Another development in digital camera technology includes the use of a single monochrome CCD chip with alternating red, green, and blue illumination to form a color image, rather than using three chips with three separate color filters. This design reduces the space requirements and takes advantage of established high-resolution monochrome CCD chip technology [15]. This design has been utilized in a digital video cystoscope (Olympus ACMI Business Group, a division of Gyrus

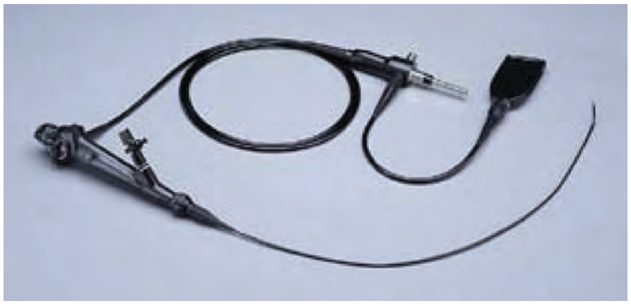

Figure 3.4 Digital ureteroscope with "chip on a stick" technology. Olympus URF-V flexible ureteroscope. (reproduced courtesy of Olympus ACMI Business Group, a division of Gyrus ACMI, Southborough, MA, USA).

ACMI, Southborough, MA, USA). More recently, this technology has been applied to flexible ureteroscopy. The Olympus URF-V flexible ureteroscope (Olympus ACMI Business Group) uses a CCD camera at its distal tip (Figure 3.4). This ureteroscope has demonstrated improved optics, including higher resolution, greater illumination, and improved color reproduction, when compared to a fiberoptic flexible ureteroscope [22]. In addition, the image is 5.3 times larger than that provided by a fiberoptic ureteroscope [22]. The URF-V has demonstrated improved subjective visibility and flexion in clinical use as well [23]. Such technology is currently being incorporated into digital laparoscopes.

Other techniques under development for image resolution enhancement include the use of complementary metal oxide semiconductor (CMOS) technology to replace the CCD sensors [24]. Both CMOS and CCD imagers are manufactured in a silicon foundry; and the equipment used is similar. But alternative manufacturing processes and device architectures make the imagers quite different in both capability and performance. It is technically feasible but not economic to use a CCD processor to integrate other camera functions, like the clock driver and signal processing. These are normally implemented into secondary chips. Thus, most CCD cameras comprise several chips. On the other hand, one of the major benefits of CMOS cameras over the CCD design lies in the high level of product integration that can be achieved through virtually all of the electronic camera functions on the same chips. Typically, a CMOS processor allows lower power usage and lower system cost. This technology is currently being used for digital ureteroscopy [25]. The Gyrus ACMI Invisio DUR-D digital flexible ureteroscope (Olympus ACMI Business Group) uses a CMOS imaging sensor coupled to a prism at its distal tip. The image is transmitted via nine wires through the scope to the camera control unit. The ureteroscope also has two light emitting diodes (LEDs) at its tip. This digital ureteroscope was shown to have superior resolution and contrast discrimination to standard fiberoptic ureteroscopes [26]. Another of its advantage is that it weighs nearly 50% less than a fiberoptic ureteroscope with the camera and light cord attached [27].

Video light sources

In addition to a CCD camera, a high intensity light source, usually either halogen or xenon, should be utilized for appropriate illumination. Certain light sources have an automatic light-sensing feature which quickly adjusts the light output as required by the camera. This automatic light adjustment feature is particularly helpful during endoscopic procedures, as the endoscope may be rapidly moved throughout the abdominal cavity or urinary tract, causing areas of too much or too little illumination. Light intensity will be automatically altered to maintain a preselected illumination level. As noted previously, some camera systems are equipped with an "automatic iris" system which will electronically increase or decrease the "aperture" of the camera shutter. If the camera system is equipped with such a light-sensing feature, there is no need for an automatic light-adjusting light source. Newer CCD- or image sensor-based endoscopic cameras feature electronic exposure. This system varies the effective exposure period (i.e. light gathering time) of the CCD as the live image is captured. Typical CCD exposure periods range from approximately 1/60 of a second to 1/10 000 of a second under very bright conditions. This electronic process can be used to maintain the brightness in the image. When the image brightness must be reduced to improve picture clarity, the image signal exposure period can be reduced electronically instead of adjusting the iris of the light source.

Shadows play an important role in depth perception and spatial orientation. Studies have demonstrated that endoscopic task performance significantly improves with video systems that provide proper illumination and appropriate shadows in the operative field [28]. Many of the current endoscopes employ a simple frontal illumination technique that produces an optically flat and shadowless image with resultant poor contrast. Newer illumination and imaging technologies provide shadow inducing systems using a single- or multi-point illumination system. One of these techniques employs the use of two independent illumination fiber bundles, with one fiber bundle ending at the front lens, as designed in conventional endoscopes, and the other fiber bundle ending behind the tip of endoscope. This configuration results in an improved image with better contrast due to shadow formation. Spatial orientation and perception between anatomic structures are considerably enhanced [24].

Video documentation systems

The ability to make permanent copies of video-monitored cases is useful in documenting these procedures from both a medicolegal viewpoint and as part of the patient's permanent medical record [29]. Hard copy pictures or video recordings of some endoscopic procedures may also be an important adjunct during follow-up, if repeat endoscopic procedures are necessary. For example, stored video images of a patient with multiple superficial bladder tumors will allow the urologist the opportunity to review "before" and "after" images after treatment has been completed.

The ability to store sequential video images on an optical disc is another advantage of utilizing video during endoscopy. It can provide the referring physician with prompt and detailed information regarding the surgical care of an individual patient. Video disks and hard copy technology now allow the presentation of patient data, graphic displays, and video images on standard photographs which can be placed in a patient's medical record. Enhanced digital printing technology is also available which allows actual video images to be printed directly into an operative report.

One such system allows multiple video images to be stored during the endoscopic procedure. At the completion of the case, various video images can be selected and are integrated directly into a dictated operative report. Such a report format proves invaluable for medicolegal purposes, as well as for dramatic documentation for the referring physician.

In addition, digitalization of video images also permits specific endoscopic procedures to be brought "online" into a computer database system and further facilitates the use of a "paperless" medical record. Once the various video images are on the computer network, they can be recalled from any workstation in the hospital that is linked to the network. Moreover, computer-manipulation (image processing) can be used to further enhance the video images [30].

Hard copy pictures

A hard copy printer generates an immediate, high quality color photograph which can be used for documentation [31]. One, four, or nine separate pictures can be stored in the printer's memory and then reproduced on the same hard copy, which allows final results to be documented for the patient or referring physician or for use in the patient's permanent record. Some of these hard copy printers also contain character-generating capabilities which allow text to be added to the video images.

Digital image storage

Surgical video systems have integrated digital image capture systems, allowing immediate capturing of still images from endoscopic procedures[18] (Figure 3.5). Alternatively, a less expensive digital still image capture adapter can be connected to endoscopic camera systems [9]. Digital still images can usually be recorded in Joint Photographic Experts Group (JPEG), tagged image file format (TIFF), or bitmap (BMP) formats. These digital images can be edited and optimized on the computer using various graphic software packages. Incorporating medical images into the patient's record, as well as creating an image library, can enhance urologic practice [32, 33]. The quality of the digital image required depends upon its purpose. Low-resolution images, in the range of 1–2 MP, can be used for email attachments or PowerPoint presentations. A higher quality image (from 3–4 MP) is more useful if a printed image is required. In cases where storage is not an issue, the image should be obtained at its highest resolution, thereby allowing for future image manipulation.

Video recording

Previously, the majority of video recordings during endoscopic procedures were performed with conven-

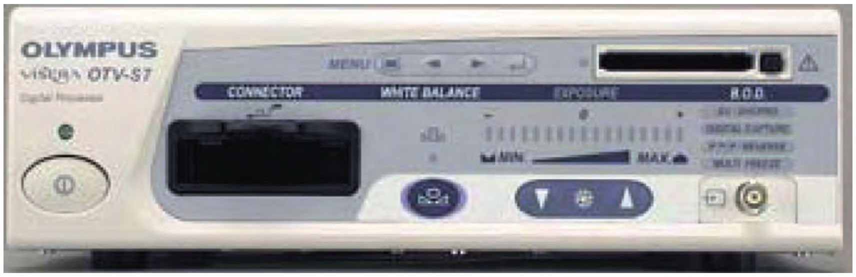

Figure 3.5 Still images and short video clips (depending on resolution) can be captured on a digital card. Direct digital video stream can be captured on a computer, digital camcorder, or digital recorder via an IEEE 1394 fire wire connector on the back panel. (Reproduced courtesy of Olympus America Inc.)

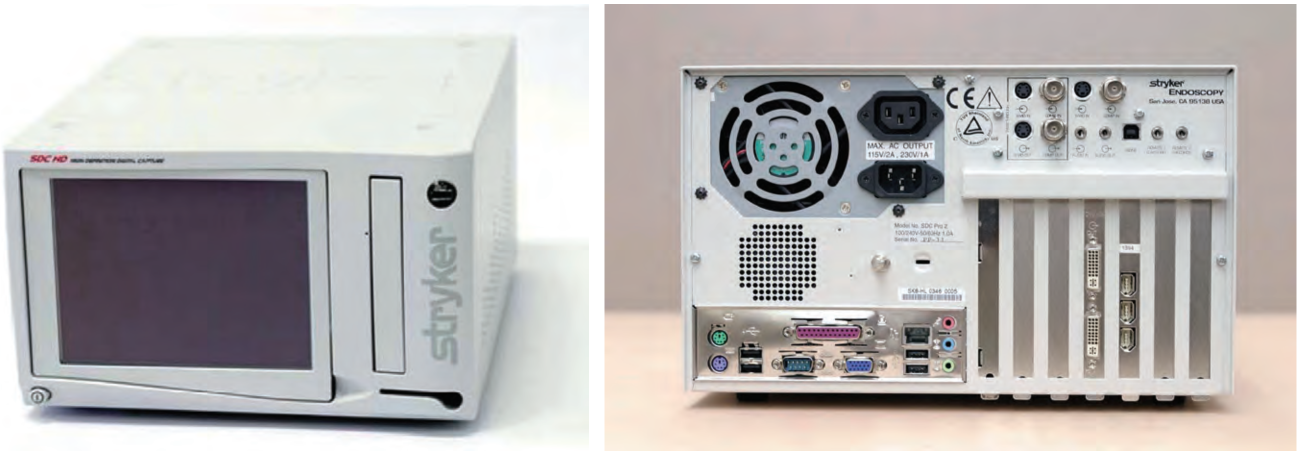

Figure 3.6 Direct DVD capture is possible, with storage in multiple formats (MPEG, AVI) offering flexibility for users (reproduced courtesy of Olympus America Inc.).

Image not available in the electronic edition

Figure 3.7 Direct recording of both digital still images and digital recordings onto USB storage devices allows for easy storage and data transfer (reproduced courtesy of © MediCapture Inc.).

tional analog VHS or S-VHS formats, which could be digitally converted. The introduction of digital video recording devices now allows video footage to be recorded directly into a digital format [i.e. Digital Video (DV), Moving Picture Experts Group (MPEG), and Audio Video Interleaved (AVI)] (Figure 3.6). Newer technology allows for storage of video and still images directly onto a portable Universal Serial Bus (USB) drive (Figure 3.7). This allows for easier storage and transfer of video images. A unique feature of this device is it allows the surgeon to confirm what is being recorded by viewing a small liquid crystal display (LCD) screen on the device. These video-capturing systems can be either part of an expensive commercial integrated video system, DV camera, DVD recorder, or a low cost personal computer with digital video capture card [34]. Digital video editing may be performed on a personal computer using various editing programs (e.g. Adobe Premiere, Movie Maker, Corell).

Smaller still digital images can be stored on different digital storage media (SmartMedia, Compact Flash, Secure Digital, Multi Media card, and Memory Stick). For larger files, especially video clips, Zip Disk (up to 750 MB), CD-ROM (up to 700 MB), and lately DVD (up to 17 GB) can be utilized. In addition, portable external hard drives are currently available with up to 1 TB. However, data storage for a large number of images can still be an issue. Picture archiving and communication systems (PACSs) are currently being utilized in an important role to store and allow easy access to medical images [35–37].

Image transmission

As we advance into the age of digital video imaging, images that have been "captured" can be immediately displayed, stored, printed, or transmitted to various locations throughout the hospital or off-site. While video images can be transmitted over standard telephone lines, the narrow bandwidth of standard coaxial copper cable limits the quality of transmitted video images. Moreover, it is often difficult to transmit full motion video over standard telephone lines. Currently, three newer modes of image transmission are being utilized in the communications industry and can therefore also be applied for the transmission of video images throughout the operating room, hospital, or to distant sites.

Fiberoptic cable

Optical fiber has rapidly replaced coaxial copper cable as the preferred mode of data transmission. Optical fiber offers significant advantages over coaxial cable as it can carry significantly more information in a small amount of space. For example, one fiberoptic fiber can carry upwards of 1.7 GB/s. This rate is thousands of times faster than data transmitted over standard coaxial cable. Moreover, optical fiber has a lower attenuation than coaxial cable and is not subject to electromagnetic interference. The major advantage of optical fiber is that large amounts of digitized information (video, audio, data, etc) can be rapidly transmitted [29]. This increased speed of transmission is especially important when dealing with the large amount of digital information contained in video images.

Wireless local area network

Recently, wireless local area networks (wireless LAN or "WiFi") have been introduced in the healthcare setting. These networks allow transmission of data and images to laptop and handheld computers throughout the patient care environment, and often form the final link between a wired hospital network and the mobile user. The current standard, 802.11n, is set by the Institute of Electrical and Electronic Engineers (IEEE), and provides for data transmission at speeds up to 150 MB/s. At these transmission rates, digital still and video image transmission becomes reasonable [38].

The advantages of a wireless network are the ability to communicate with mobile users, ease of installation without the need for construction of a wired network, and flexibility for future technologic advances. Disadvantages can include initial set-up costs and the battery requirements of mobile workstations. Concerns have been expressed about interference of wireless devices with medical devices, but interference only occurs with a few devices and only when the medical device is within 10 cm of the LAN transmitter [39]. Wireless networks have been successfully used to transmit radiologic images for interpretation, as well as a live broadcast of laparoscopic surgery to handheld computers for instructional purposes [40–42].

Satellite communications

The advent of satellite communications has also allowed the transmission of digitized video images to remote areas that are not linked by coaxial cable or fiberoptic conduit. Satellite communications currently allow the performance of teleconferencing and telemedicine, where voice and video images can be almost instantaneously transmitted to remote sites, to allow interactive communication. Currently, it is believed that a combination of fiberoptic cable and satellite transmission systems may globally link distant operating rooms to major medical centers, thereby greatly facilitating performance of advanced endoscopic procedures. An experienced surgeon can assist or perform complex endoscopic procedures at the remote site (telepresence surgery).

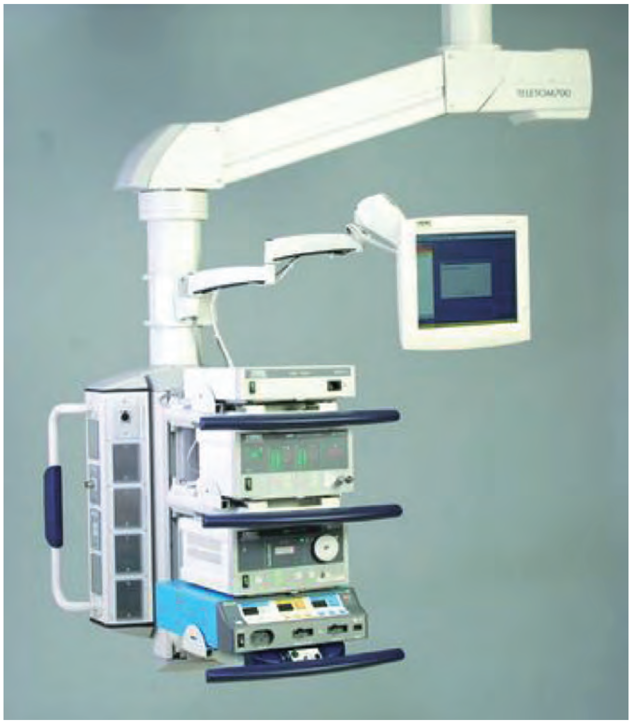

Figure 3.8 Video carts contain video camera electronics, light source, and various recording devices (reproduced courtesy of Olympus America Inc.).

Video system set-up

Video cart

An essential part of any video system should be the video cart. This cart is an integral component for the entire system, which allows easy transport of the video documentation system from one surgical suite to another (Figure 3.8). The video cart should have room to hold the video camera electronics, the light source, and various recording devices such as a hard copy printer or DVD recorder. Moreover, some video carts will also have room to hold the laparoscopic insufflator as well as electrocautery units. The cart needs to be adequately secured during storage to prevent equipment loss, and to have the capability to hold CO_2 tanks which will be needed during laparoscopic procedures.

Video set-up

Traditionally, our standard operating room set-up places the video cart, which contains a video camera and recorder, television monitor, and xenon light source, directly across from the operating surgeon. In addition, a second high resolution video monitor is placed on the other side of the table to be used by the assistants. If only one video monitor is available, it should be placed directly at the end of the operating table. All endoscopic procedures in our endoscopy suite and operating rooms are performed entirely off the video monitor(s).

With the advent of more current operating room designs, the fundamental differences between open and endoscopic or laparoscopic surgery have been recognized. Whereas in the past endoscopists and laparoscopists relied upon mobile carts traveling from room to room, today specialized rooms provide dedicated carbon dioxide lines, preventing the need to change tanks in mid-operation. Another issue relating to suboptimal operating room design is the effect of imperfect ergonomics on surgeon comfort from a musculoskeletal standpoint. Many recent studies have demonstrated significant stressors to the surgeon induced by laparoscopy, many of which are related to monitor placement, camera holding, trocar placement, and table position and height [43–46]. Operating room enhancements, such as ceiling-mounted monitors and designs focused on the endoscopic and laparoscopic surgeons, allow for versatility in the ergonomics surrounding minimally invasive urologic procedures (Figure 3.9). Whether or not these specially designed operating rooms improve upon musculoskeletal complications in surgeons has yet to be determined, but some studies indicate that this is the case and that overall operating room efficiency is improved as well [47, 48]. A novel addition to the operating room of the future may incorporate high-resolution binocular face-mounted devices, such as have been explored at the bench level, thus providing less surgeon neck/back strain and improved visualization and satisfaction compared to conventional standard video monitors [49].

Future directions of endoscopic video systems

As previously noted, significant advances have been made in the development of video imaging technology for minimally invasive surgical procedures. A major limitation of current video systems, however, continues to be the two-dimensional images provided to the surgeon. Although the image quality itself is quite satisfactory, the lack of depth perception may impair delicate dissection or suturing during minimally invasive procedures, as motion parallax and other indirect evidence of depth is relied upon to judge the correct spatial relationship of the objects in the operating field. At times, the tissues have to be actually touched in order to gauge depth, thereby significantly reducing the speed and precision at which minimally invasive surgical procedures can be performed.

Moreover, as advanced reconstructive minimally invasive surgical procedures are developed, some training opportunities become limited. This lack of "routine" cases makes it often difficult for the medical student, house officer, and practicing physician to become familiar with more complex minimally invasive surgical maneuvers. Therefore, a way to simulate such complex procedures would be beneficial to aid in the training of the endoscopic surgeon.

Three-dimensional (3D) video systems as well as high-definition television have been recently introduced to significantly improve visualization during minimally invasive surgical procedures. In addition, virtual reality techniques have been developed, which allow enhanced image processing of videoendoscopic procedures as well as the development of surgical simulations to aid in training of complex surgical maneuvers. The following sections will review these enhanced imaging technologies for endoscopic surgery.

3D Video imaging

3D video imaging enhances the ability to perform delicate endoscopic maneuvers, such as dissection or precise suturing [50]. Moreover, those who are observing have a better understanding of the surgical anatomy because of the 3D image.

Principles of 3D stereoendoscopy

In normal human vision, depth perception is a factor taken for granted. Normally, the eyes will accommodate and converge in such a way that there is intersection of the visual axes of both eyes. This intersection is known as the point of fixation. When viewed by both eyes, lateral disparity causes the viewed object to be projected in slightly different orientations on the retina of the right and left eyes. The human brain interprets this disparity on a small region of the retinal fovea (called the Panum's region) as depth information. The brain then fuses these images to give the perception of depth, and this effect is called stereopsis [51].

Accommodation is the ability of the human eyes to clearly visualize objects which are both near and farther away. The eyes converge, and the lens increases its dioptic strength so that the object is brought into sharp focus on the retina. The nearest an object can be to the eye and still be in focus is called the near point, while the farthest it can still be in focus is called the far point. The region of depth is the area between the near and far points. This ability to accommodate is preserved when viewing objects with a 3D video system.

As noted, when viewing a particular object with binocular vision, it is normally perceived in three dimensions. However, if one eye is closed, a "flattening" of the image might be noted. Owing to the capability of the "image center" within the brain to capture and recall

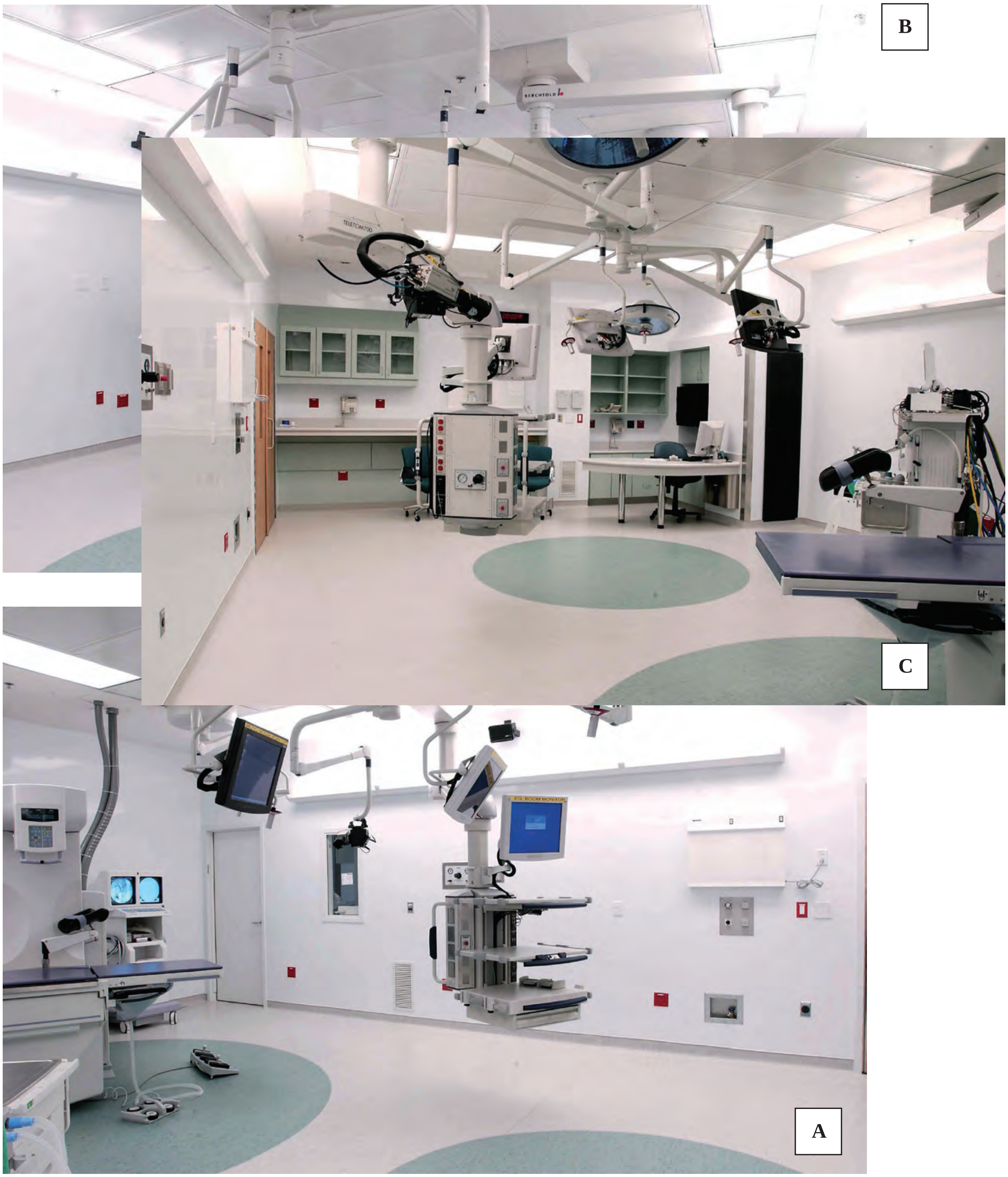

Figure 3.9 Current (future) endoscopic/laparoscopic operating room (OR). (A) Ceiling-mounted flat panel monitors. Builtin endoscopy table with adequate room for laparoscopic applications. (B) Touch panel control allowing for routing of different source images on different monitors. Wall plug in for C-arm integration with room monitors. Wall panel integrating OR with audiovisual center allowing for video capture, integration with conference rooms, and teleconferencing. (C) Ceiling-mounted camera for external footage (reproduced courtesy of Stryker).

images, the viewed object may appear with somewhat limited depth (i.e. 2.5D). This ability to visually process two-dimensional (2D) flat images off a standard video screen and view them in a partial 3D manner may be a significant factor in the ability of experienced endoscopic surgeons to adequately perform endoscopic surgical tasks. This innate ability to perceive standard flat video images in three dimensions is significantly reduced when the surgeon is confronted with a scene which has not been viewed before. Therefore, the introduction of 3D video systems should facilitate the performance of endoscopic surgical procedures, especially those which require intricate dissection or reconstructive techniques.

To mimic normal 3D vision, a 3D video system must therefore convey separate off-set images to each eye. The figure is captured in a slightly different orientation by the stereoendoscope and, after image processing by the brain, it appears as a 3D object. Any 3D video system must therefore incorporate the principles of stereopsis [51, 52]. One potential limiting factor of 3D endoscopic systems is that the normal interpupillary distance for human vision is approximately 60 mm, while the maximum separation of two objective lenses in a standard 10-mm endoscope is approximately 8 mm. Various endoscopic designs, however, have accounted for this disparity, still allowing for adequate capture and display of 3D images.

Stereoendoscopic image processing

Most of the 3D stereoendoscopic video systems currently available have four basic principles of stereoendoscopic image processing in common: image capture, conversion of 60–120-Hz images, presentation of left and right images on a single monitor; and separation of the left and right eye images [53]. The following sections will describe in more detail current stereoendoscopic equipment utilized for 3D endoscopic surgery.

Stereolaparoscope

Stereolaparoscopes are of two basic designs: a two-lens optical system or a single optical channel. The dual-lens systems individually capture slightly different images of the operating field, much like the right and left eye will capture slightly different views of a single image. The parallel optical channels then present the separate images to the left and right eye camera systems.

In contrast, the single optical channel design captures the image with a single objective lens at the distal end of the endoscope. At the proximal end of the endoscope, adjacent to the stereo camera, the image is split into separate left and right eye images. One advantage of this single optical channel design may be higher resolution and more light for the 3D video image than presented by the smaller two optical systems contained in the dual optical channel endoscopes.

Image splitter

The single-channel 3D video systems utilize a device to split the images captured by the left and right half of the single-lens endoscopes. In some systems, the image splitter is incorporated into the proximal end of the single-channel stereoendoscope [54].

Stereo camera

Most 3D video systems contain a stereo camera head which incorporates two separate CCD image sensors (usually half-inch CCD chips) that capture the images from the stereolaparoscope. These images from the stereolaparoscope are viewed by the left and right eye cameras, just as two separate images are presented to the left and right eyes during normal binocular vision.

3D image processing

Most 3D video systems contain a 3D conversion unit which processes the images obtained from the left and right eye cameras. These conversion systems allow the left and right eye images to be alternately synchronized on a single stereoscopic monitor at 120 Hz (60 Hz for each eye). If the images are presented slower than 120 Hz, substantial "flicker" on the video monitor may be noticed. Moreover, slower speeds of video display may also cause vertigo.

The 3D video conversion systems will allow viewing of live 3D procedures, and recording of surgical cases in three dimensions with subsequent playback of these cases in three dimensions. While initial 3D video systems recorded left and right eye images on separate video recorders, current systems can capture both on a single video. The left and right eye images are stored on a single "video frame," which greatly simplifies the recording, playback, and editing of 3D endoscopic images. The image processing unit and standard 3D video monitor are both necessary to view the previously recorded endoscopic images.

3D display

The 3D conversion system will sequentially display the left and right eye images on the 120-Hz 3D video monitor. However, in order to view the left and right eye images on a single monitor, the images must be separated. One method involves "active" LCD shutter glasses. These glasses are synchronized by an infrared emitter which is located on top of the video monitor. As the left eye image is projected on the video screen, the emitter will control the shutter glasses so that the right eye is closed and the left eye is open. Alternatively, when the right eye is open, the left side of the LCD glasses is blackened and the right eye image appears on the video screen. The advantage of this active system is that more light is projected to each eye and therefore the 3D image appears brighter. However, the active LCD shutter glasses require a battery, and are somewhat heavy and quite expensive (approximately US$1000).

Alternatively, "passive" polarized glasses may be worn to view the left and right eye images from the single video monitor [54]. This type of system requires a special polarizing filter on the video screen which will "rotate" the left and right eye images in different orientations, thereby allowing simultaneous viewing of the left and right images. The passive polarized glasses have the advantages of significantly cheaper cost than the active LCD shutter glasses and are more comfortable to wear, but the polarizing glasses present a slightly darker 3D image than the active glasses.

An alternative to dual projection is the presentation of the two images independently to the left and right eye, much like looking through field binoculars. The images can be displayed on small screens set at the focal distance for the surgeon and mounted on an ergonomic headset [55]. This technology is currently available as part of the DaVinci robotic system [56].

Recording and projection of 3D video images

Early 3D video systems required two separate recorders to capture the left and right eye images. However, the majority of systems now currently utilize a 3D conversion system that will alternatively store the left and right eye images on a single disk. This system design allows efficient capture of 3D video footage for play back at a later time.

There are also 3D video projectors available which will alternatively display left and right eye images on a large video screen. (Such 3D video projectors are ideal for large group demonstrations and for educational purposes. As with separation of images during viewing on a 3D video monitor, the 3D video projector can utilize active LCD shutter glasses or a passive polarized lens systems.

Advantages and limitations of 3D videoendoscopy

The increased depth of field afforded by 3D endoscopic video systems facilitates intricate minimally invasive surgical procedures [57, 58]. Addition of a third dimension allows better recognition of tissue layers and may facilitate complex maneuvers, such as laparoscopic suturing or knot tying [59]. Indeed, skill tests performed assessing laparoscopic suturing and knot tying have demonstrated a 25% increase in speed and accuracy of these laparoscopic tasks when utilizing a 3D video system as compared to a standard 2D endoscopic video system [60]. Some investigations claim that 3D video systems only facilitate surgical tasks in inexperienced laparoscopic surgeons. It appears that the reduction in time required to perform various minimally invasive surgical procedures may not be as dramatic in those individuals who have a large amount of experience with standard 2D video systems during endoscopic surgery [55]. Some studies suggest that a higher resolution video system might be more advantageous than having 3D endoscopic imaging [61–63]. The major current use of 3D imaging systems is during laparoscopic, robotic surgical procedures, to allow for true stereoscopic imaging [64–66].

Late model 3D videoendoscopic systems compared with initial 3D components provide greatly improved 3D viewing of minimally invasive surgical procedures. Yet, they still provide reduced resolution and lower-light images as compared to standard single- or three-chip 2D video cameras. The decrease in image brightness and resolution is due to the fact that most 3D video systems use two optical channels that are significantly smaller than a single-lens system in a standard 10-mm laparoscope. Moreover, since most 3D video systems incorporate two separate camera systems, the camera head is significantly larger than a single-camera system and, therefore, more cumbersome to work with during minimally invasive surgical procedures.

Cost continues to be a limitation of 3D videoendoscopy. Most 3D video systems are two to three times more expensive than standard 2D endoscopic video cameras. While more costly, the enhanced depth perception produced by 3D endoscopes has been demonstrated to improve the performance of minimally invasive surgical procedures [67, 68]. 3D imaging also facilitates the training of minimally invasive surgery and may lessen the learning curve of these technically demanding procedures [69]. It is anticipated that 3D video imaging will significantly improve the performance of current endoscopic procedures as well as facilitate the development of more advanced, minimally invasive surgical techniques [50].

High-definition television

The development of high quality image display systems has become essential during endoscopic surgery. Previous studies have demonstrated that the inherent optical quality of most endoscopes and CCD cameras exceeds the display resolution of standard television [70]. With the limited resolution of current analog NTSC, phase alternation line (PAL), and sequential color and memory (SECAM) monitors, there is a demand for higher resolution image display systems. One such digital display system is HDTV. The most common HDTV formats used in the USA are 1080p and 1080i. The "p" represents progressive scanning, meaning that each scan includes every line for a complete picture, while the "i" signifies interlaced scanning with each scan including alternate lines for half a picture. These scan rates translate into a frame rate of up to 240 frames/s, eight times that of conventional television monitors. HDTV offers greatly enhanced picture quality with improved image resolution. HDTV pixel numbers range from 1 to 2 million, compared to NTSC, PAL, or SECAM's range of 300 000 to 1 million. The other significant feature of the HDTV format is its wider aspect ratio (the width-to-height ratio of the screen) of 16:9 as compared with NTSC, PAL, and SECAM screens, which have an aspect ratio of 4:3. Studies have suggested that the wider aspect ratio provides more information for the viewer, thereby enhancing both diagnostic and therapeutic interventions [9, 63].

High-definition digital laparoscopes are currently available for use and offer many significant advantages over standard definition (SD) laparoscopes. Surgeons have subjectively rated HD images superior to SD images during laparoscopy in both the laboratory and clinical setting [71]. One recent study performed an objective comparison of performance characteristics between the Olympus HD 10-mm laparoscope (Olympus ACMI Business Group) and the Olympus SD 10-mm zero-degree laparoscope [72]. The HD laparoscope had improved resolution, decreased distortion, greater depth of field, and improved lumenis flux when compared to the SD laparoscope. Given the importance of visual cues in performing laparoscopic surgery, these improvements could be of great significance. Laparoscopy performed with an HD camera in combination with an HD monitor can improve the performance of surgical tasks, specifically laparoscopic knot tying, which requires precise depth perception [71].

The future application of high-definition imaging (HDI) technology would improve endoscopic image resolution based on CCD chips. The European standard HDI chip resolution is 2 340 250 pixels, resulting in 1250 horizontal lines. HDI has the advantage of resolution enhancement for image brilliance and the augmentation of secondary depth clues such as shadows. With the use of CMOS technology to replace CCD sensors, image resolution may be further enhanced [24].

The improved resolution and color separation of HDI provides better diagnosis and enhances the effect of secondary spatial cues, leading to easier orientation, particularly if the images are combined with improved illumination. Despite its current high cost, the price of HDTV cameras and monitors will continue to decline as newer HDTV products come onto the consumer market. With further optimization of size and weight of the camera system, HDTV will likely become a standard feature for endoscopic imaging and display during endoscopic and laparoscopic procedures (Figure 3.10).

Virtual reality

Endourologic procedures require specific training to achieve competency. Often, there are reduced training opportunities for residents due to a limited number of clinical cases. Moreover, ethical and cost issues may further limit the use of animal or cadaver models for training purposes [73–75]. While hands-on training using bench models can successfully teach laparoscopic skills, it precludes the ability to vary clinical conditions [76]. Moreover, inanimate simulators lack the realistic feel of living tissue.

Advances in virtual reality (VR) simulation offer a practical tool for urologists to practice various endourologic procedures, from the basic to the most complex, in an inanimate but dynamic, life-like environment without risk to patients or ethical issues. Accurate reproduction of anatomic structures provides a realistic VR surgical simulation. Models should also provide appropriate tactile feedback and spatial cues.

As endoscopic procedures require little in the way of complex anatomic and tactile feedback, one of the earliest simulators in urology was a VR ureteroscopy simulator (Immersion Medical, Gaithersburg, MD, USA) [73, 74, 77]. This simulator allowed urologists to explore the ureter and kidney for pathologic processes, specifically, stones and tumors. However, this early simulator was limited due to lack of true anatomic representation and inadequacy in computer graphics. Advances in computing power, VR graphics, and physical modeling techniques resulted in a new endoscopic simulator (URO Mentor system, Symbionix, Tel Aviv, Israel) [78]. This is a commercially available VR modular endoscopic simulator that provides virtual cystoscopy and ureteroscopy procedures using either rigid or flexible endoscopes. Realtime fluoroscopy with simulation of C-arm control and viewing of fluoroscopic images of injected contrast can also be simultaneously combined with endoscopic procedures. Various endourologic procedures, including cystoscopy, retrograde pyelography, insertion of guidewires, ureteral stenting, ureteroscopy, stone fragmentation, and fragment removal using various tools, can be realistically simulated. Studies have demonstrated that use of this VR simulator resulted in more rapid acquisition of ureteroscopic skills in urologic trainees [79–81] In fact, studies of both laparoscopic and ureteroscopic simulators have demonstrated a significant reduction in the learning curves to perform both routine and complex endoscopic procedures.

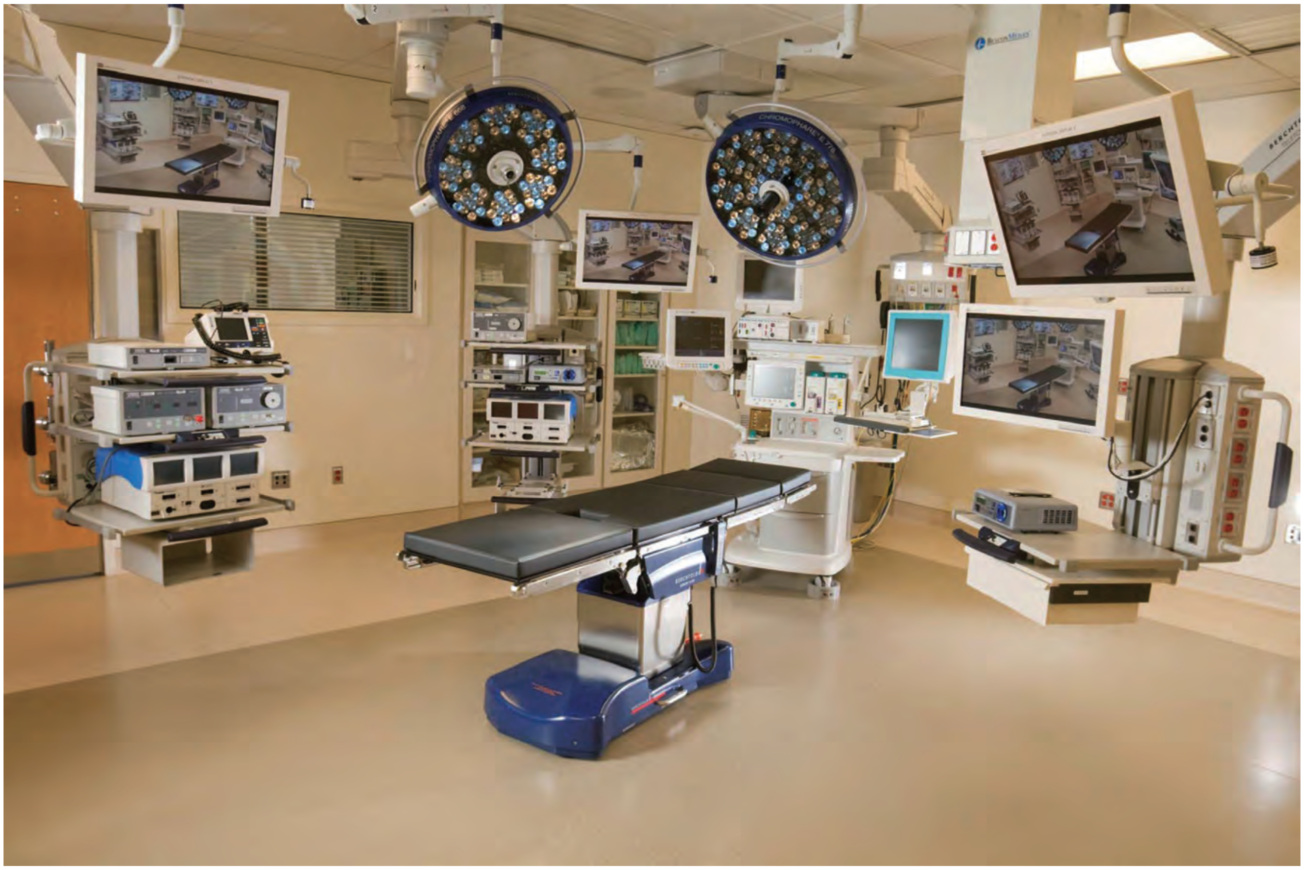

Figure 3.10 Current operating room with high-definition television (HDTV) monitors.

Endourologic skills can also be validated using VR simulation [75, 82].

Further advances in computer and software technology have allowed VR simulation to become more realistic for the performance of laparoscopic procedures [83–86]. The LapMentor system (Symbionix) is a VR system for the training of laparoscopic skills and surgical procedures. This system has been validated as a training modality for laparoscopic skills [87]. It has been demonstrated in a randomized, double blinded study to improve basic laparoscopic skills of surgical residents [88]. Training residents with a laparoscopic VR simulator to a certain level of proficiency can decrease intraoperative errors and operating time during their initial live surgical experience, thus reducing the learning curve [89, 90]. Similar to the aviation industry, VR simulation will likely be incorporated into the training, testing, and credentialing of endourologists and laparoscopic surgeons over the next 5–10 years.

Image-guided surgery

Augmented reality (AR) involves the integration of preoperative radiologic imaging with realtime intraoperative surgical views. It allows the surgeon to “see” subsurface information which is inaccessible through ordinary endoscopic imaging. Augmented reality and imaged-guided surgery (IGS) have many potential advantages over conventional endoscopic surgery. AR has the potential to replace the loss of haptic feedback in robotic and laparoscopic surgery by allowing surgeons to see anatomic and spatial relationships which are not obviously apparent through standard or 3D views. In addition, AR and IGS have the potential to predict surgical results [91]. These features have the potential to minimize the loss of healthy tissue while maximizing oncologic efficacy.

Various techniques have been described for the implementation of IGS and AR. Realtime virtual sonography (RVS) has been described, allowing synchronization of preoperative computed tomography (CT) or magnetic resonance (MR) images with intraoperative realtime ultrasound images [92, 93]. The system displays the realtime ultrasound image and the corresponding image of a 3D reconstructed CT or MR image. This technology is especially useful for percutaneous ablative procedures for the kidney or prostate.

Other investigators have reported on the use of AR for laparoscopic partial nephrectomy [93]. They utilized an optical tracking system for their surgical instruments combined with a computer workstation to overlay preoperative 3D reconstructed images onto their surgical view. For laparoscopic partial nephrectomies, the images were displayed with colored zones corresponding with the tumor and various margins. Other techniques have been described for coordinating the preoperative images to the intraoperative view. One system placed navigation in the target organ for better localization and to account for organ movement [94]. This technique has been coined as the "inside-out tracking system." The tracking system was able to overlay images onto the operative field with a 0.5-mm error margin.

AR has also been applied to robotic assisted laparoscopic partial nephrectomy [95]. The system allows overlay of 3D models constructed from preoperative CT scans onto the 3D intraoperative video recordings. The advantage of this system is it does not require external tracking devices. Another model for AR utilized the da Vinci robot system as a single localizer [96]. This system demonstrated decreased removal of benign tissue in an *in vitro* model.

All of these systems currently allow for 3D reconstructed, preoperative images to be displayed onto realtime endoscopic surgical views. The major limitation is accounting for organ motion and deformity. The future of AR and IGS is predictive surgical navigation. Gill and Okimura described a surgical radar and a surgical body gravitational positioning system (GPS) [92]. Surgical radar involves displaying color-coded zones over the realtime image of an intended surgical target. The trajectory of an instrument, e.g. endoscopic scissors, can be used to predict whether the current path of that instrument will violate an undesirable structure, such as a tumor. Surgical body GPS allows for monitoring of realtime organ position. The surgeon can be alerted to how realtime movement of the organ alters the line of excision for an intended target. The aim of this technology is to maximize normal tissue preservation and oncologic efficacy.

Internet and telemedicine

In recent years, telemedicine, defined as the use of electronic information and communication technologies to provide and support healthcare from a distance, has become an important aspect in patient care. Advances in digital imaging, high speed computer connections, and the widespread availability of the Internet have allowed a steady growth of telemedicine within urology [97]. The applications of telemedicine have grown from a simple sharing of information to actual performance of surgeries remotely [98].

Digital still images and streaming video/audio can be transmitted over the Internet using a variety of available modalities, including Integrated Services Digital Network (ISDN) at 128 kB/s, T1 lines at 1.54 MB/s, coaxial cable at up to 6 MB/s, and Asymmetric Digital Subscriber Line (ASDL) at 1–3 MB/s [9, 11, 32]. More recently, video transmission has been described utilizing Digital Video Transfer System (DVTS) software over the Internet [99, 100]. DVTS has been used successfully for realtime video conferencing with data transfer speeds up to 30 MB/s over the Internet and up to 100 MB/s over a LAN [99, 101]. The system described by Huang *et al*. could deliver live video of 720 x 480 pixels at 30 frames/s [99]. The advantages of DVTS are preserved image quality and relatively low cost [99, 101]. In addition, the use of a virtual private network (VPN) router allows for encryption of the images without degradation of the quality [99]. This is important for maintaining patient confidentiality.

Telemedicine is most commonly utilized for educational purposes and for telementoring. It is now routine for endourologic surgeries ranging from ureteroscopy to robotic-assisted laparoscopic cystectomies to be broadcast live at educational meetings. The surgeries are performed remotely around the world and the video and audio are projected live to attendees at these meetings. This is an efficient way to disseminate new techniques to large numbers of practitioners. Transmitting live or prerecorded surgical procedures can be done for smaller video conferencing between institutions [100, 101]. The cost requirements for these live video transmissions have decreased considerably. All that is required is access to the Internet, DVTS software, which can often be obtained for free, a digtial video recorder, and monitors to view the procedures. Another educational application of telemedicine is video journal submissions. Urologic journals are now accepting video submissions for publication. This goes well beyond descriptive text for dispersing new techniques and procedures. These video submissions can not only be viewed online, but they can be downloaded for increased portability.

Telementoring involves realtime guidance and instruction by an experienced surgeon to a less experienced surgeon at a remote location utilizing video and audio connections [102]. Kavoussi and colleagues reported on their initial laboratory experience with telemedicine in 1994 [103, 104]. In 2000 they reported on their clinical experience telementoring laparoscopic surgery in Rome, Italy [105]. During these five laparoscopic cases, a more experienced team in Baltimore, USA, oversaw procedures performed in Rome in real time. They offered advice, provided quality control, and even operated instruments remotely. The cases performed included a laparoscopic nephrectomy. More recently, the group in Baltimore aided in the performance of a laparoscopic varicocelectomy and a percutaneous nephrolithotomy in Brazil [106]. Images and audio were transmitted utilizing ISDN lines, which provided video rates of 15 frames/s with a signal delay of 700 ms. Newer technology utilizing DVTS can transmit video at 30 frames/s with a signal delay of 280 ms [100]. Agarwal *et al*. recently reported on the novel use of the RemotePresence-7 (InTouch Health, Sunnyvale, CA, USA) robot as a remote intraoperative consultant [107]. This robot has two digital cameras, an audio microphone, and is mobile. It can be operated remotely over a broadband Internet connection using a laptop and a remote control. In addition to being able to view the entire operating room, it also has a video input which provides a direct connection with a videoendoscope, allowing the remote physician to view directly the images seen by the operating team. The cost of the robot is approximately $150 000, which can be prohibitive.

What does the future hold? Sterbis *et al*. likely provided us with a glimpse of the future with their recent publication describing telerobotic laparoscopic radical nephrectomies in a porcine model [98]. The animals and robot were located in Sunnyvale, CA, USA and the remote surgeons were either located in Cincinnati, OH, USA or Denver, CO, USA. A da Vinci console was located at both the local and remote site. The remote surgeons controlled two of the three robotic arms and a local surgeon controlled the remaining arm. The video and robotic signals were transmitted over the Internet using nondedicated T1 lines. Commercial video coding/decoding systems (CODEC) were used at both sites to code and decode the information. There was a time delay between 450 and 900 ms and difficulty with visualization in one procedure. Despite these limitations, all four procedures were successfully performed. With continued advancement of technology, remote off-site, real-time telesurgery will become a reality.

Conclusions

The application of video technology to endoscopic procedures provides several advantages in both the teaching and private practice settings not previously available to the urologist. Improved magnification and image quality facilitates performance of the procedure by the surgeon, as well as coordination of the assistants and ancillary personnel to provide a smoother, safer, and potentially shorter operation. Video monitoring facilitates teaching both during and after the procedure, as well as providing preoperative patient education. Video accessories provide immediate documentation for the patient's medical record, for use by the referring physician, or for the patient's own interest. Additionally, video and hard copy documentation provides an invaluable teaching aid for patients and medical personnel. Moreover, videoendoscopic procedures also increase the safety of the procedure for the operating urologist.

As newer technologies, such as HDTV and 3D videoendoscopy, become more widespread, an increasing number of videoendoscopic procedures will be performed. The dissemination of the surgical skills needed to perform these surgical procedures is becoming increasingly important. Technologies such as VR simulation and telementoring will become commonplace in the near future for the training of future urologists. These technologies allow for more rapid acquisition of skills necessary to perform complex endourologic and laparoscopic procedures in a safe environment with reduced risks of adverse events for patients. Future technologies such as IGS should only further improve the safety and efficacy of videoendoscopic procedures. With the advent of new technology for video imaging and documentation, patient care provided by the endourologist and minimally invasive surgeon should rapidly improve.

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CHAPTER 4

Preoperative Antibiotics and Prevention of Sepsis in Genitourinary Surgery

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Introduction

Septic complications in urologic surgery constitute one of the most feared and life-threatening situations in current urologic practice In this chapter we will describe the importance of correct preoperative work-up, including adequate antibiotic prophylaxis and intraoperative measures to prevent the development of infectious adverse events and sepsis, as well as the identification of early postoperative events that could lead to sepsis in specific conditions, in order to achieve a prompt diagnosis and reduce morbidity and mortality.

Urinary tract infections (UTIs) and urolithiasis head the list of urologic healthcare cost in the USA [1]. In an Internet-based study conducted by the European Urologic Association (EAU) in 194 different European and Asiatic urology departments, nosocomial UTIss (NUTIs) accounted for 11% of healthcare-associated infections. The most common presentation was asymptomatic bacteriuria in 29%, followed by cystitis in 26% and pyelonephritis in 21%. Twelve percent of all cases presented as urosepsis. Among those patients with NUTIs, almost 80% had a prior history of urologic surgery; endourologic procedures in 50%, open or laparoscopic surgery in 45%, and prostate biopsies in 5% [2]. These data suggest that preventive measures, such as a strict preoperative evaluation and correct antibiotic prophylaxis in surgical patients, must be improved.

The prophylactic use of antibiotics can reduce the risk of surgically-related infection. Recently both the EUA and American Urological Association (AUA) published guidelines and recommendations for best practice in antibiotic prophylaxis in urologic surgery [3–5]. These guidelines are extremely helpful to standardize the administration of antibiotics prior to surgery. However, local practice should be based on or adjusted according to local or even hospital microbiologic patterns and requirements, so it is crucial that each center and department reviews regularly its infection patterns and antibiotic resistance.

There is no uniformity in the literature in the definition of infection versus sepsis, which may account for the wide range of incidences reported. After any diagnostic or therapeutic urologic procedure, UTIs can be present as a simple bacteriuria with limited clinical symptoms or they can result in severe sepsis or even septic shock. It is difficult to predict in which patient a serious complication will develop, but several publications describe potential risk factors that can contribute to this scenario. It is crucial to recognize patients at risk of complications with a complete preoperative evaluation in order that there is a prompt diagnosis and proper treatment in the event of a postoperative infectious complication.

Pathogenesis of urosepsis

Urosepsis is defined as a sepsis caused by UTI; this occurs in 7–25% of all septic cases [6]. An infectious complication is triggered during urologic surgery when urinary bacteria and their products enter the bloodstream via vascular, lymphatic, or urothelial disruption. Manipulation of infected urine or infection stones with an increase in pressure mainly in the collecting system causes an intense liberation of bacteria and endotoxins via direct absorption, pielovenous–lymphatic

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or pielotubular backflow, and forniceal rupture, and these events then trigger a systemic inflammatory response [7].

There is a neurohumoral generalized pro- and anti-inflammatory response. This begins with cellular activation of monocytes, macrophages, and neutrophils that interact with endothelial cells through numerous pathogen recognition receptors [8]. A further host response includes the mobilization of plasma substances, such as tumor necrosis factor (TNF), interleukins (ILs), caspases, proteases, leukotrienes, kinins, reactive oxygen species, nitric oxide, arachidonic acid, platelet activating factor, and eicosanoids. TNF-α and IL-1 are the most important proinflammatory cytokines and exhibit similar biologic properties. They influence the temperature regulatory centers in the hypothalamus, resulting in fever. They also have an effect on the formation reticularis in the brain stem, which renders the patient somnolent and comatose. Release of adrenocorticotropic hormone (ACTH) in the pituitary gland is increased, which stimulates the adrenal gland. These factors also stimulate hematopoietic growth factors, which leads to the formation of new neutrophils and the release of stored ones. The neutrophils are additionally activated and produce bactericidal substances, such as proteases and oxygen radicals. B and T lymphocytes are stimulated for the synthesis of antibodies and cellular immune reaction. In the continuing septic process however, apoptosis of B cells, CD-4 helper cells, and follicular dendritic cells causes an anti-inflammatory immune suppression, called transient immune paralysis [9].

Activation of the complement and coagulation cascades further amplifies this chain of events. There is microvascular injury, thrombosis, and loss of endothelial integrity (capillary leak), resulting in tissue ischemia. This diffuse endothelial disruption is responsible for the multiple organ dysfunction and global tissue hypoxia that accompany severe sepsis/septic shock [10].

Bacteriology of urinary infections and sepsis

The pathogens associated with UTIs and urosepsis have not varied greatly over the last decades [11, 12], and concern centers around the considerable changes in resistance patterns. A continuous assessment of local patterns is important in order to establish the most appropriate antibiotic regimens to prevent infectious complications most efficaciously.

Escherichia coli remains the single most common microorganism to cause urinary infection. This is followed by *Klebsiella* and *Proteus* spp., frequently associated with stone disease. Furthermore, the increasing presence of Gram positive bacteria such as *Enterococcus* and *Staphylococcus* should be noted.

DasGupta *et al*. reported that 40% of urology inpatients had Gram positive organisms, *Enterococcus* accounting for 27% [13]. Several reports have shown that other organisms have increased not only their incidence, but also their resistance to antibiotics commonly used in urology, including trimethoprim, quinolones, cephalosporins, and aminoglucosides, such as gentamicin; this is the case for *Pseudomonas aeurginosa, methicillin-resistant Staphylococcus aureus* [14], *Serratia* spp., and *Clostridium difficile.* The resistance of *Pseudomona* to quinolones is reported in up to 20% of urology inpatients, with *multiresistant Pseudomona* outbreaks encountered in endourologic units [15]. Kashanian *et al*. [16] recently reported in a retrospective analysis 25% resistance of *E. coli* to ciprofloxacin. This rise in resistance of urinary pathogens towards quinolones has been reported worldwide and might be the consequence of its overuse due to its efficacy in treating other infections and uncomplicated UTIs, as well as its misuse as prophylaxis in some urologic diagnostic procedures.

General measures of sepsis prevention in genitourinary surgical patients

In recent years, the incidence of sepsis has increased, but the associated mortality has decreased, suggesting improved management of patients [17]. Besides correct management, the role of prevention is of great importance and it is imperative to identify preoperative risk factors, apply adequate prophylaxis, and try to minimize intraoperative risks, in order to reduce the incidence of septic episodes or allow early recognition of the features that can lead to one.

The EAU in its Guidelines on Urological Infections recommends the following basic preventive measures of proven efficacy in any urologic patient undergoing surgery [5]:

- Isolation of all patients infected with multiresistant organisms to avoid cross-infection.
- Prudent use of antimicrobial agents, both in prophylaxis and in treatment of established infections, to avoid selection of resistant strains. Antibiotic agents should be chosen according to the predominant pathogens at a given site of infection in the hospital environment.
- Reduction in hospital stay. It is well known that long inpatient stays prior to surgery lead to a greater incidence of nosocomial infections.
- Early removal of indwelling urethral catheters, as soon as allowed by the patient's condition.
- Nosocomial UTIs are promoted by bladder catheterization as well as by ureteral stenting.
- Antibiotic prophylaxis does not prevent stent colonization, which appears in 100% of patients with a permanent ureteral stent and in 70% of those temporarily stented.

- Use of closed catheter drainage and minimization of breaks in the integrity of the system.
- Use of the least invasive method to release urinary tract obstruction until the patient is stabilized.
- Attention to simple everyday techniques to assure asepsis, including the routine use of protective, disposable gloves, frequent hand disinfection, and infectious disease control measures to prevent cross infections.

Preoperative evaluation

All patients who are being considered for genitourinary surgery should be evaluated with a complete medical history, physical examination, and laboratory tests, including an obligatory urine culture; this will identify those patients with a high risk for development of an infectious complication [18].

Risk factors for infectious complication

There are well recognized risk factors that for academic purposes can be categorized under the following headings (Table 4.1).

Related to the patient

There are several patient characteristics known to increase the risk of infectious complication after surgery. Patients who are immunosuppressed secondary to diverse causes, among others those with malignant or autoimmune diseases receiving chemotherapy or chronic use of corticosteroids usually have impaired infection resistance. Also patients of advanced age or poor nutritional status, with diabetes, obesity, significant kidney or liver diseases, and female patients have a higher risk [6]. Other related factors are the presence of a coexistent infection at another site at the time of surgery or prolonged hospitalization.

Related to urinary tract diseases

Urologic patients are at risk of developing infectious complications because of specific factors related to urinary diseases or their management, both increasing the possibility of colonization and chronic bacteriuria. Risk factors in urologic patients are: anatomic anomalies, voiding dysfunction, urinary diversion, active UTI, obstruction of the urinary tract, stone disease, indwelling catheters, and endogenous material, such as ureteral stents.

Many of these patients will have a positive urine culture and must receive preoperative antibiotics appropriately tailored to culture-specific organisms; at the end of treatment urinary evaluation must be repeated. Rao *et al*. reported that bacteriuria and pyuria are risk factors for bacteremia; they also found that preoperative bacteriuria had a positive predictive value (PPV) of 0.53 for detection of endotoxemia, another important risk factor for the development of urosepsis [19].

Related to procedure

Any procedure performed in patients with urolithiasis is high risk for postoperative infection due to bacterial colonization of the urinary tract, infection stones, or urinary drainage obstruction and indwelling catheters. A lengthy operation or high intrapelvic pressures during endourologic procedures, such as percutaneous or retrograde renal surgeries, carries a high risk of postoperative infection. Finally, open or laparoscopic surgeries, which involve the gastrointestinal or genital tract, such as urinary diversions or vesicovaginal fistula repair, also should be considered high-risk procedures for infection.

These factors frequently act in an additive manner, compounding their impact. The likelihood of bacterial invasion is also affected by the amount of bacteria at the

Table 4.1 Risk factors associated with postoperative infectious complications in genitourinary surgery.

Related to patient	Related to urinary tract diseases	Related to procedure
Immunosuppression: Malignancy Autoimmune diseases Chronic corticosteroid use Diabetes mellitus Poor nutritional status Severe kidney or liver dysfunction Advanced age Female Distant coexistent infection Prolonged hospitalization	Chronic bacteriuria Voiding dysfunction Urinary diversion Obstruction Stone disease Indwelling catheters Endogenous material (ureteral stents) Anatomic anomalies Impaired urinary flow	Stone disease management Incisional therapy Surgery of long duration Involvement of genital tract Involvement of gastrointestinal tract Prosthesis

site of the surgical procedure. All procedures invading the urinary tract are considered "clean–contaminated." The likelihood of bacterial invasion is increased if bacteriuria is present or good wound preparation and surgical techniques are not employed [9].

Antibiotic prophylaxis

Prophylaxis means a brief course of antibiotics administered before or at the start of an intervention, and is used to minimize the infectious complications resulting from diagnostic and therapeutic interventions. While the rationale for the use of antibiotics is well accepted, possible side effects and development of antimicrobial resistance patterns are potential risks. Therefore, an antibiotic prophylaxis policy should be well considered and based on high levels of evidence [3].

Surgical antimicrobial prophylaxis is recommended only when the potential benefit exceeds the risks and anticipated costs; it has been demonstrated in a variety of settings that surgical antimicrobial prophylaxis, by reducing the incidence of surgical site infections, reduces costs. Conversely, excess and/or inappropriate antimicrobial prophylaxis increases costs, which is reversed by measures to improve compliance with evidence based recommendations [20].

In considering prophylactic treatment, the surgical site and the properties of the antimicrobial agent should be taken into account. The agent should achieve serum and tissue levels that exceed the minimum inhibitory concentration for organisms characteristic of the operative site. Furthermore, the optimal agent should have a long half-life so as to maintain sufficient serum and tissue concentrations for the duration of the procedure without the need for redosing. It should be safe, inexpensive, and unlikely to promote bacterial resistance [4].

For prophylactic antimicrobial administration to be optimally effective, timing and dosing are critical. Infusion of the first dose should begin within 60 min of the surgical incision (with the exception of 120 min for intravenous fluoroquinolones and vancomycin). Correct dosing is equally important. Some drugs should be adjusted to the patient's body weight. Oral administration is as effective as the intravenous route for antibiotics with sufficient bioavailability. This is recommended for most interventions, when the patient can easily take the drug between 1 and 2 h before intervention. Additional doses are required intraoperatively if the procedure extends beyond two half-lives of the initial dose [21]. With few exceptions, the published literature suggests that antimicrobial prophylaxis is unnecessary after wound closure or upon termination of an endoscopic procedure; in most cases, antimicrobials should be given in a single dose, or at least discontinued within 24 h of the end of the procedure.

Three circumstances in which a longer duration of antimicrobials is frequently considered include the placement of prosthetic material, the presence of an existing infection, and the manipulation of an indwelling tube [22]. In cases where an existing infection is present, a therapeutic course of antimicrobials should be administered in an attempt to sterilize the field. In the absence of pre-existing bacterial colonization, there is no evidence that prophylaxis should extend beyond 24 h following a procedure. In cases where prolonged catheterization follows the procedure (e.g. radical prostatectomy), antimicrobial therapy at the time of catheter removal may be therapeutic rather than prophylactic, since colonization has likely occurred. An alternative is to culture the urine 24–48 h prior to the intended catheter removal, and administer culture-directed therapy. This is not practical in cases of catheterization for only 48–72 h. An option then is to administer antimicrobial treatment empirically [4].

The use of preoperative antibiotics can reduce the risk of surgically related infection. Table 4.2 summarizes the recommendations for best practice in antibiotic prophylaxis in urologic surgery from the recently published EAU and AUA guidelines [4, 5].

Preoperative antibiotics and preventive measures of sepsis in specific procedures

Endourologic surgery and shock-wave lithotripsy

Although infection or sepsis may occur despite a sterile preprocedure urine culture, every effort should be made to sterilize the urinary tract before instrumentation. Preoperative treatment with culture-specific antibiotics and subsequent documentation of successful treatment is imperative.

While having a preoperative negative urine culture is desirable for all endourologic procedures, this is not always possible, mainly because of stone or urinary tract colonization. In these cases, appropriate antibiotic therapy should start at least 1 week before the planned procedure.

Shock-wave lithotripsy

The use of prophylactic antimicrobial treatment in patients who undergo shock-wave lithotripsy (SWL) is debated in the literature. The AUA recommends that all patients who are submitted to treatment with SWL receive prophylaxis, quoting a meta-analysis that showed prophylaxis reduced postprocedural bacteriuria from 5.7% to 2.1% [4]. In contrast, the EAU does not recommend the routine use of antibiotic prophylaxis, but suggests the use of prophylaxis in cases at risk of

Table 4.2 Recommended antimicrobial prophylaxis in genitourinary surgery and procedures (modified from [4, 5]).

	Indication		Antimicrobial scheme			
Procedure	AUA	EAU	First choice	Alternative	Duration	Remarks
Diagnostic procedures						
Cystography Cystoscopy Ureteroscopy Uodinamycs	If risk factors	If risk factors	Fluoroquinolone or Second-generation cephalosporin or TMP–SMX	Aminoglycoside ± ampicillin Amoxacillin/clavulanate	≤24 h	If urine culture is negative, antimicrobial prophylaxis is not necessary
Prostate biopsy	All	All	Fluoroquinolone or TMP–SMX	Aminoglycoside + metronidazole or clindamycin	≤72 h	
Endourologic surgery and shock-wave lithotripsy						
Shock-wave lithotripsy	All	In patients* at risk	Fluoroquinolone or TMP–SMX or second-/third-generation cephalosporin	Aminoglycoside ± Ampicillin Amoxacillin/clavulanate	≤24 h	*Patients with ureteral stent, nephrostomy Obstruction and infection stone
TURP/TURBT	All	Only in patients at risk**	Fluoroquinolone or TMP–SMX or second-/third-generation. cephalosporin or aminopenicillin/BLI	Aminoglycoside Ampicillin First-generation cephalosporin Amoxacillin/clavulanate	≤24 h	**Consider in large necrotic tumors
Ureteroscopy	All	Only in patients at risk	Second-/third-generation cephalosporin or TMP–SMX or aminopenicillin/BLI Fluoroquinolone	Aminoglycoside ± ampicillin First-generation cephalosporin Amoxacillin/clavulanate	≤24 h	
Percutaneous renal surgery	All	All	Second-/third-generation cephalosporin or TMP–SMX or aminopenicillin/BLI	Ampicillin/sulbactam Fluoroquinolone First-generation cephalosporin	≤24 h	Length of short course to be determined, intravenous route suggested

Open or laparoscopic surgery						
Clean operations	If risk factor	All	First–generation cephalosporin	Clindamycin	Single dose	Consider in high risk and short postoperative catheter treatment
Clean–contaminated (opening of urinary tract)	All	All	Second-/third-generation cephalosporin or aminoglycoside + metronidazole or aminopenicillin/BLI	Ampicillin/sulbactam Fluoroquinolone	Single perioperative course	
Contaminated (involving intestine)	All	All	Second-/third-generation cephalosporin Aminoglycoside + metronidazole or clindamycin	Ampicillin/sulbactam Ticarcillin/clavulanate Pipercillin/tazobactam Fluoroquinolone	≤24 h	For surgery involving the colon, bowel preparation with oral neomycin plus either erythromycin base or metronidazole can be added
Implanted prosthetic devices	All	All	Aminoglycoside _ First-/second-generation cephalosporin orvancomycin	Ampicillin/sulbactam Ticarcillin/clavulanate Pipercillin/tazobactam	≤24 h	

TURP, transurethral resection of prostate; TURBT, transurethral resection of bladder tumor; TMP–SMX, trimethoprim–sulfamethoxazole; AUA, American Urological Association; EAU, European Association of Urology; BLI, beta-lactamase inhibitor.

Table 4.3 Key points in prevention of infection/sepsis in shock-wave lithotripsy.

1. Identify risk factors
2. Rule out active UTI preprocedure
3. Obtain preoperative negative urine culture (ideally)*
4. Antimicrobial prophylaxis (AMP) if one of the following:**
    - Obstruction
    - Presence of an indwelling stent or catheter
    - Infection stones
    - Periprocedure stone or urologic manipulation (stone mobilization, double-J stent insertion)

*In bacterial persistence or chronic bacteriuria administer at least three days of culture specific antibiotics before shock-wave lithotripsy.

**American Urological Association guidelines recommends AMP in all cases.

Table 4.4 Key points in prevention of infection/sepsis in transurethral resection of prostate (TURP)/transurethral resection of bladder tumor (TURBT).*

1. Identify high-risk patients
2. Discard active UTI preprocedure
3. Obtain a preoperative negative urine culture (ideally)**
4. Antimicrobial prophylaxis (AMP) in all cases:***
    - Maintain closed urinary drainage system
    - Avoid prolonged catheterization (>3 days)

*Applicable to other transurethral procedures with manipulation.

**In chronic bacteriuria or catheterized patients administer 3–7 days of culture-sensitive antibiotics before surgery.

***For TURBT, EAU guidelines recommend AMP only in the presence of risk factors or large and/or necrotic tumors.

infection, such as those with an indwelling stent or catheter, or infection stones [5].

Skolarikos *et al.*, from the results of a meta-analysis, also suggest prophylaxis is useful only in patients with the above-mentioned risk factors, as well as in patients who undergo preprocedure stone or urologic manipulation at the time of SWL [23]. More recently, Duvdevani *et al*. have supported these recommendations based on similar findings [24].

Although the rate of bacteremia post SWL is reported to be as high as 14%, the rate of sepsis is less than 1%, and the use of prophylaxis remains controversial [25]. The key points in prevention are listed in Table 4.3.

Transurethral surgery (Table 4.4)

Transurethral resection of prostate

UTIs and other infectious complications can be present in 1–26% of patients treated with transurethral resection of prostate (TURP). Risk factors associated with postoperative bacteriuria are operative time, disconnection of the closed urine drainage system, prolonged postoperative catheterization (≥3 days), and preoperative catheterization (within 1 month prior to surgery) [26, 27]. TURP is the most studied procedure regarding the use of antibiotic prophylaxis. Two large meta-analyses have been published, including 38 and 32 randomized clinical trials (RCTs), respectively, and both concluded that the benefit obtained from antibiotic prophylaxis in TURP is sufficiently well demonstrated [28, 29]. The incidence of bacteriuria is reduced (26% to 9%), as is that for clinical sepsis (4.4% to 0.7%). Wagenlehner *et al*., in a large, prospective multicenter study, compared two antibiotics regimens versus a control group; they found that the patients receiving antibiotics showed lower levels of bacteriuria compared with controls and demonstrated that the presence of bacteriuria post TURP (CFU $>10^4$/mL) is a risk factor for infectious complications [30]. There was no statistical difference between antibiotic regimens. Bacteriuria is not considered to be an infectious complication but the last study showed that there is a correlation between bacteriuria and the development of infectious complications.

The AUA guidelines recommend the use of antimicrobial prophylaxis in all patients. The suggested antimicrobial prophylaxis is fluoroquinolone or trimethoprim–sulfamethoxazole as antimicrobial of first choice, and alternatively a first- or second-generation cephalosporin, aminoglycosides ± ampicillin or amoxicillin/clavulanate, before the start of TURP and until less than 24 h postoperatively [4]. The EAU guidelines recommend a very similar antibiotic regimen in all patients other than those at low risk or with a small prostate [5].

Transurethral resection of bladder tumor

The AUA guidelines recommend the same regimen of antimicrobial prophylaxis mentioned above for TURP in all patients undergoing transurethral resection of bladder tumor (TURBT). In contrast, the EAU guidelines recommend that antimicrobial prophylaxis for TURBT is unnecessary unless the patient has some risk factors for infectious complications, or a large tumor requiring a prolonged resection time, or a necrotic tumor. Scientific evidence supports the recommendation by the EAU in two well conducted studies that did not showed any difference between antibiotics and placebo in term of reduce the rate of bacteriuria [31, 32]. More recently, Yokohama *et al*. in a prospective, randomized study in patients with no risk factors for complications corroborated these findings; no differences were found in terms of infectious complications between groups given antibiotics or placebo. The authors concluded that antibiotics might be deferred and only given to patients who develop postoperative infections [33].

Other transurethral procedures

Other transurethral procedures involving manipulation, like bladder biopsy, laser prostatectomy, and internal uretrotomy, may be similar in terms of tissue trauma, and the AUA guidelines suggest that data regarding TURP and TURBT could be extrapolated to these procedures.

Ureteroscopy

As with other endourologicl procedures, the routine use of antimicrobial prophylaxis for ureteroscopy in patients with a sterile preoperative urine culture is controversial. Assessment of urine for sterility by midstream urine specimen (MSU) culture and sensitivity (C&S) is recommended by most endourologists as an essential prerequisite for endoscopic stone treatment. Nevertheless, MSU cultures do not always correlate with obstructed urine or stones, and sepsis may present in 1% of cases who have a negative MSU culture. Mariappan *et al*. in a prospective study cultured MSU, renal pelvic urine, and obstructing ureteric stones from patients who had undergone ureteroscopic lithotripsy [34]. Clinical bacteremia was seen in 19%. Of these, 58.3% developed features of systemic inflammatory response syndrome (SIRS). Blood and stone C&S were positive in 25% of cases and pelvic urine C&S was positive in 66.7%, but none had a positive MSU C&S ($P = .04$). Because of the potential for infection or the presence of infection stones, antibiotic prophylaxis is indicated when ureteroscopy is performed for treatment of urinary tract calculi. Few randomized and prospective trials have explored the role of antibiotic prophylaxis in ureterolithotripsy. Knopft *et al*. compared a single preoperative dose of levofloxacine versus placebo, and found the rate of postoperative significant bacteriuria to be significantly higher in the placebo group than in the group given prophylaxis [35].

Indications for antibiotics are less clear for diagnostic ureteroscopy or treatment of tumors. The risk of infection and sepsis, albeit low (3.4% and 0.3–2%, respectively), outweighs the potential benefits, such as cost savings, that may be associated with no antibiotic administration for therapeutic proposes [36]. Current AUA and EAU recommendations for antimicrobial prophylaxis are given in Table 4.2.

Table 4.5 Key points in prevention of infection/sepsis in therapeutic ureteroscopy.

1. Identify high risk patients
2. Discard active UTI preprocedure
   - *Never* perform stone manipulation or incision therapy in active UTI
   - Relieve urinary obstruction, treat infection, and carry out a staged treatment
3. Ensure a preoperative negative urine culture (ideally)*
4. Antimicrobial prophylaxis in all cases
5. Maintain low intrarenal pressure during procedure.

Options:
   - Periodic drainage through ureteroscope or use of ureteral access sheath or angiographic catheter
   - Continuous or intermittent bladder drainage

*In chronic bacteriuria administer at least 3 days of culture-sensitive antibiotics before instrumentation.

Modifiable intraoperative factors may influence infectious complications (Table 4.5). During ureteroscopy, the hydrostatic pressure generated by the irrigation fluid results in bacterial and endotoxin translocation into the systemic circulation; therefore, a low-pressure irrigation system can reduce the incidence of systemic infection. Only enough irrigation to maintain adequate visibility should be used, and renal pressure should be kept as low as possible with the use of a ureteral access sheath (UAS) or angiographic catheter, or periodic drainage of the collecting system through the ureteroscope. In addition, continuous or intermittent bladder drainage with a small-caliber bladder catheter will help maintain low intrarenal pressures during ureteroscopy [36]. Auge *et al*. found that by using a UAS during ureteroscopic stone surgery, pressures in the urinary tract could be significantly reduced. Flexible ureteroscopy was performed with and without the aid of the UAS while pressures were measured via the nephrostomy tube connected to a pressure transducer. With the ureteroscope positioned in the distal ureter, the mean intrarenal pressure without the UAS was 60 mmHg versus 15 mmHg with the UAS; with the ureteroscope in the renal pelvis the pressures were 94.4 mmHg and 40.6 mmHg, respectively [37].

Percutaneous renal surgery

Percutaneous renal surgery has a low reported incidence of urinary sepsis (0.3–1%), but a high mortality rate (66–80%). It is generally agreed that patients who are scheduled for percutaneous nephrolithotomy (PCNL) must have a negative urine culture before surgery. Unfortunately, this is not always possible to adhere to because of stone or urinary tract colonization; in these patients, appropriate antibiotic therapy

Table 4.6 Key points in prevention of infection/sepsis in percutaneous renal surgery.

1. Identify high-risk patients
2. Discard active UTI preprocedure
   - *Never* perform stone manipulation or incision therapy when active UTI!
3. Ensure sterile urine preoperatively (ideally)*
4. Antimicrobial prophylaxis in all cases
5. Stop procedure if purulent fluid is obtained at puncture, leave a nephrostomy tube, and stage treatment**
6. Maintain low intrarenal pressure during procedure:
   - Use only enough irrigation to maintain adequate visibility
   - Use a wide renal access sheath, ideally 4 F wider than nephroscope
7. Limit quantity of irrigation fluid and operative time

*In chronic or asymptomatic bacteriuria administer at least 7 days of culture-sensitive antibiotics before surgery.
**Obtain pelvic urine culture and treat infection completely.

should start at least 1 week before the planned procedure (Table 4.6).

Results of urine cultures from patients with stones are not predictive of stone bacteriology, especially in those with struvite stones. Therefore, this group should receive broad-spectrum antibiotic therapy that is specific to the cultured bacteria but also likely to be effective against urease-producing organisms residing in the stone.

Mariappan *et al*. demonstrated that stone and pelvic urine cultures obtained during surgery are better predictors of potential urosepsis than bladder MSU [38]; they found that bladder urine cultures were positive in 11.1% of cases versus 35.2% and 20.4% of stone and pelvic urine cultures, respectively. Stone culture showed the greatest PPV (0.7). Infected bladder urine did not always carry identical bacteria to those found in the upper tract. Patients with pelvic- or stone-positive cultures showed a relative risk for urosepsis at least four times greater than the rest of the cohort. In this study, bladder urine did not predict SIRS. Also, they found that preoperative hydronephrosis and stones larger than 20 mm correlated with positive stone and pelvic urine cultures.

The published literature suggests that antimicrobial prophylaxis is unnecessary after wound closure or on termination of an endoscopic procedure, but because PCNL can be associated with a pre-existing infection, infectious stone, or manipulation of an indwelling catheter, the subsequent course of antimicrobials that is therapeutic rather than prophylactic might extend beyond 24 h from the conclusion of the procedure. In the absence of pre-existing bacterial colonization, there is no evidence that prophylaxis should extend beyond 24 h. In cases where prolonged catheterization follows the procedure (i.e. nephrostomy tube), antimicrobial therapy at the time of catheter removal may be therapeutic rather than prophylactic, because colonization likely has occurred. A recommended antimicrobial regimen is given in Table 4.2.

Renal pelvic pressure (RPP) greater than 30 mmHg has been shown to result in pyelovenous–lymphatic backflow. Troxel and Low, in a prospective study that included 31 patients, found that during PCNL pressures greater than 30 mmHg were recorded in only eight (26%) patients and no association was seen between RPP and postoperative fever [39]. Contrary to this, Zhong *et al*. demonstrated that mean intrapelvic pressure greater than 20 mmHg and accumulated time of RPP greater than 30 mmHg may cause enough backflow to contribute to bacteremia and postoperative fever [40]. Low RPP during surgery is achieved using an open low-pressure access system, such as operating through an Amplatz sheath (operating instrument 4 F sizes smaller than the access sheath). Inflow of irrigant should be at gravity and never pressurized. We also recommend the use of forced diuresis (furosemide 20 mg at the beginning of irrigation and every 60 min of surgery and irrigation time) to reduce further the pyelorenal reflux that potentially causes fluid overload and bacteremia. Others factors that have been related to postoperative fever and risk of bacteremia are long operative time, large stone burden, and large amounts of irrigating fluid.

Manipulation of infected stones can cause sepsis due to endotoxemia. McAleer *et al*. measured endotoxins levels in renal stones and found markedly higher levels in infection stones [41]. Interaction of bacteria with different intracorporeal lithotripters may have antibacterial effects. *In vitro* studies have shown a decrease of bacteria viability after use of intracorporeal lithotripsy and laser [42]. Our group has reported recently that extracorporeal shock-wave or intracorporeal lithotripsy, using all the alternatives currently available, are significantly effective at reducing the viability of bacteria located inside artificial stone models, including struvite stone models infected with *Proteus mirabilis* [43–45]. Whether this bactericidal effect is desirable is still to be answered, because reduction in the number of bacteria may represent an increase in the presence of proteins/endotoxins liberated from bacterial cell lysis, therefore increasing the risk of urosepsis.

In the presence of an obstruction at the ureteropelvic junction (UPJ) or intrarenal segments (stone, stricture, or tumor), infected urine may be encountered despite previous negative cultures of the voided urine. In such instances, treatment has to be postponed, the urine cultured, and the renal collecting system drained under antibiotic coverage until eradication of the infection is documented. According to Ramsey *et al*. in a recent evidence-based review [46], the effects on the resolution of infected hydronephrosis are similar if a ureteral stent or a nephrostomy tube is used, nevertheless Mokhmalji *et al*., in a prospective randomized study, reported prolonged fever and catheter placement time in the group of patients treated with ureteral stent, and suggest that percutaneous nephrostomy is superior to ureteral stents for diversion of hydronephrosis [47].

Small case series have been reported that explore the possibility of continuing the surgery even if purulent urine is encountered incidentally. Aron *et al*., in a group of 19 patients, reported no difference regarding the incidence of postoperative fever or sepsis between patients with one-stage versus staged surgery with collecting system drainage and 3–7 days of intravenous antibiotic coverage before a second procedure [48]. Hosseini *et al*. divided 45 patients into two groups: in group 1 (n = 29), stones were removed during the first session; and in group 2 (n = 16), a nephrostomy tube remained in place, and stone removal was accomplished 3–5 days later when results of urine and nephrostomy fluid cultures were negative [49]. They reported no intraoperative or postoperative complications, other than transient fever in 10.3% and 12.5% in groups 1 and 2, respectively. In spite of these recent reports, there is neither sufficient evidence nor well designed clinical trials to recommend other conduct than performing a staged procedure with drainage and broad-spectrum antibiotic therapy until infection has resolved.

Open and laparoscopic urologic surgery

Surgical wound classification into the categories clean, clean–contaminated, contaminated, and dirty seems as relevant to urologic surgery as it is for general surgery [50].

Clean surgery

This category involves surgery performed in uninfected tissues without opening of the urinary tract and with primary closure of the wound. Montgomery *et al*., in a prospective but nonrandomized trial, compared 424 hand-assisted laparoscopic nephrectomies with and without antimicrobial prophylaxis (cephalosporin preoperatively), and found that omission of antibiotic prophylaxis was significantly associated with an increased rate of incision site infections (13% vs 5.4%) [51]. Steiner *et al*. randomized a group of 83 patients undergoing open transabdominal radical nephrectomy to a single dose of intravenous third-generation cephalosporin (n = 39) versus no antimicrobial prophylaxis (n = 44) and found a significantly lower overall infection rate in the prophylaxis group (7.7% vs 27.3%) [52].

Clean–contaminated surgery

The urinary tract is entered under controlled conditions and there are no infected tissues or bacteriuria. Surgery involving bowel tissue is also classified as clean–contaminated. According to the EAU guidelines for UTI, prophylactic antibiotics are not recommended for open procedures that do not involve bowel segments, except in patients who are at increased risk of infection, as occurs with long-term urinary drainage. The expected rate of febrile UTI in surgeries that enter the urinary tract is close to 10% without prophylaxis; antimicrobial prophylaxis can be expected to significantly reduce this rate to 2–3% [53]. Regarding the optimal duration of perioperative prophylaxis, one randomized and controlled trial confirmed that 1 day of intravenous second-generation cephalosporin was as effective as 4 days of the same agent in the prevention of postoperative infections after radical prostatectomy [54]. Stranne *et al*. also found in a prospective study that a single dose of antibiotic (a quinolone) given before radical retropubic prostatectomy appears to be sufficient prophylaxis [55].

Contaminated and dirty surgery

The presence of a nontreated infection, including UTI, should be considered as contaminated urologic surgery. When pus is present, the surgery is labeled dirty.

In *contaminated* and *dirty* operations, antimicrobial agents are given with a therapeutic intention. Infected urine is a very high risk factor for both surgical site infections in, for example, open prostatectomy, and febrile UTI after TURP. Casey *et al.* reported an incidence of infectious complication of 20% in patients with chronic bacteriuria undergoing major urologic surgery, and they found that wound infections were as common in patients whose urine cultures revealed multiple unsuspected organisms as in those who were resistant to the perioperative antibiotics [56]. Patients with an indwelling catheter, nephrostomy tube, or other stent device should be considered as having bacteriuria and must be treated in advance (between 3 and 7 days prior to the operation) in order to favor sterile urine at the time of surgery. The patient should be covered well beyond the intervention (7–10 days or longer), depending on the type of operation and patient factors [57].

Since infectious complications are potentially serious when they involve prosthetic material, antibiotic coverage is advocated irrespective of surgical category [50].

Use of antibiotics in patients with indwelling catheters, stents, and drainage tubes

The most important risk factor in the development of catheter-associated bacteriuria is the duration of catheterization. Most episodes of short-term catheter-associated bacteriuria are asymptomatic and are caused by a single organism. Multiple organisms tend to be acquired in patients catheterized for more than 30 days.

The clinician should be aware of two priorities: the catheter system should remain closed and the length of catheterization should be minimal. While the catheter is in place, systemic antimicrobial treatment of asymptomatic catheter-associated bacteriuria is not recommended, except for some special cases. Routine urine culture in an asymptomatic catheterized patient is also not recommended because treatment is in general not necessary. Antibiotic treatment is recommended only for symptomatic infections.

Long-term antibiotic suppressive therapy is not effective. Antibiotic irrigation of the catheter and bladder is of no advantage. Routine urine cultures are not recommended if the catheter is draining properly. A minority of patients can be managed with the nonreturn (flip) valve catheter, which avoids the need for a closed drainage bag. Such patients may exchange the convenience of on-demand drainage for an increased risk of infection.

Alternatives to indwelling urethral catheters that are less prone to cause symptomatic infection should always be considered. In selected patients, suprapubic catheters, condom drainage systems, and intermittent catheterization are preferable to indwelling urethral catheters [5]. Intermittent catheterization is recommended whenever the patient is able to self-practice this alternative. Prophylactic antimicrobials have not been demonstrated to be beneficial in patients undergoing clean intermittent catheterization [57]. The rate of bacteriuria even in short-term catheterized patients is 5–10% for each day that the catheter is in place [58].

When continuous urinary drainage is required after surgery, perioperative antibacterial prophylaxis is not recommended unless a complicated infection requiring treatment is suspected. Asymptomatic bacteriuria (bacterial colonization) is only to be treated prior to surgery or after removal of the drainage tube. Treatment of a patient at the time of removal of an external urinary catheter should be based on culture-directed antimicrobials. An analysis in the Cochrane Database of Systematic Reviews concluded that there is limited evidence that antimicrobials during the first 3 postoperative days, or from postoperative day 2 until catheter removal, reduces the rate of bacteriuria and other signs of infection in surgical patients [59].

In patients with indwelling double-J stents, two RCTs showed that the rate of bacterial colonization depends directly on underlying pathologies, time of stenting, and female sex [60, 61]. Low-dose antibiotics for patients with temporary double-J stents are not recommended and have been shown to increase the risk of acquiring bacterial resistance [62, 63]. Recent advances in stent design have lead to the development of some drug-eluting catheters with the aim of reducing the biofilm and thus the stent colonization. In a rabbit model, triclosan reduced bacterial growth and *P. mirabilis* survival, preventing stent-related UTIs [64].

Postoperative sepsis: early identification and initial treatment

Early recognition and management of sepsis optimizes outcome. Therefore, patients in whom this problem is suspected after genitourinary surgery should be prioritized and receive timely care.

To diagnose sepsis and severe sepsis/septic shock as early as possible, it is necessary to have clear definitions of infection, organ dysfunction, and global tissue hypoxia, and to recognize the clinical and laboratory findings that are indicative of these conditions.

Sepsis is defined as the presence of SIRS caused by a documented or suspected infection. SIRS is defined as the presence of two or more of the following: (1) temperature greater than 38°C or less than 36°C; (2) heart rate greater than 90 beats/min; (3) respiratory rate greater than 20 breaths/min (or $PaCO_2 < 32$ torr); and (4) white blood cell count greater than $12\,000/\text{mm}^3$ or greater than 10% immature band forms.

Severe sepsis is defined as the presence of sepsis and one or more organ dysfunctions. Organ dysfunction can be defined as acute lung injury; coagulation abnormalities; thrombocytopenia; altered mental status; renal, liver, or cardiac failure, or hypoperfusion with lactic acidosis.

Septic shock is defined as the presence of sepsis and refractory hypotension, i.e. systolic blood pressure less than 90 mmHg and unresponsive to a crystalloid fluid challenge of 500 mL.

As mentioned above, clinical and laboratory recognition of septic problems is mandatory. Procalcitonin is a propeptide of calcitonin, but lacks hormonal activity. During generalized infections with systemic manifestations, its level may rise considerably. In contrast, during severe viral infections or inflammatory reactions of non-infectious origin, procalcitonin levels show no or only a moderate increase. Its exact site of production during inflammatory response is still unknown. The documentation of high levels of early biochemical markers, such as procalcitonin and protein C, in the initial postoperative period may help identify a severe inflammatory

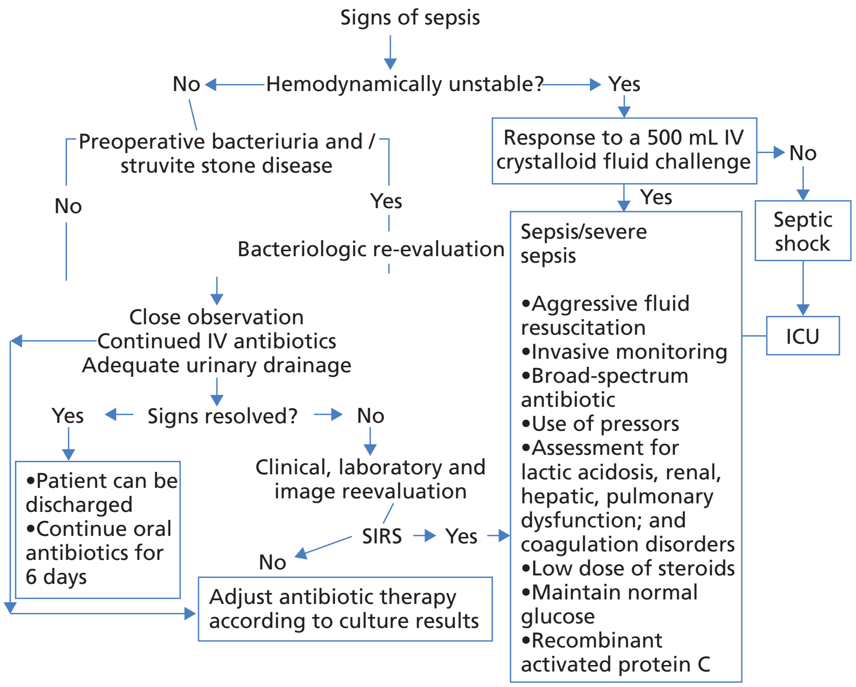
Signs of sepsis
Hemodynamically unstable?
No
Yes
Preoperative bacteriuria and / struvite stone disease
No
Yes
Bacteriologic re-evaluation
Response to a 500 mL IV crystalloid fluid challenge
No
Yes
Septic shock
ICU
Sepsis/severe sepsis
•Aggressive fluid resuscitation
•Invasive monitoring
•Broad-spectrum antibiotic
•Use of pressors
•Assessment for lactic acidosis, renal, hepatic, pulmonary dysfunction; and coagulation disorders
•Low dose of steroids
•Maintain normal glucose
•Recombinant activated protein C
Close observation
Continued IV antibiotics
Adequate urinary drainage
Signs resolved?
Yes
No
•Patient can be discharged
•Continue oral antibiotics for 6 days
Clinical, laboratory and image reevaluation
SIRS
Yes
No
Adjust antibiotic therapy according to culture results

Figure 4.1 Postoperative management of a patient suspected of or diagnosed with sepsis. ICU, intensive care unit; SIRS, systemic inflammatory response syndrome.

response to surgical stress from bacteremia, SIRS, or sepsis/septic shock, and prompt the institution of adequate and opportune therapeutic measures [65].

Appropriate therapy is a continuum of infection management ranging from drainage (maintaining indwelling catheter or opening the nephrostomy tube in cases of percutaneous renal surgery and broad spectrum antibiotics, to aggressive fluid resuscitation and invasive monitoring with medical management in the intensive care setting until the causative agent is found and eradicated (Figure 4.1).

Continuous monitoring of vital signs, pulse oximetry, urine output, and initial laboratory testing to assess the severity of global tissue hypoxia and organ dysfunction, including assessment for lactic acidosis, renal and hepatic dysfunction, acute lung injury, and coagulation abnormalities, should be instituted as soon as possible in patients in whom severe sepsis/septic shock is suspected to facilitate the earliest recognition of this condition.

The usual bacteria cultured from urinary sources are aerobic Gram negative bacilli and enterococci. Appropriate cultures (including blood and urine) should be obtained before the adjustment of antibiotics. At this point, it is important to reanalyze urine cultures that were obtained preoperatively or during surgery and, based on their results, redirect antibiotic therapy. If results are not available, empiric broad spectrum antibiotics should be initiated as soon as possible. Suggested primary regimens include the usage of ampicillin/gentamicin, or piperacillin–tazobactam, or carbapenems (doripenem, imipenem, or meropenem); the duration of treatment is determined by the patient's clinical response. It is imperative to modify the antibiotic regimen to a culture directed one when possible.

If severe sepsis/septic shock is recognized, besides empiric antibiotic therapy, prompt treatment in the intensive care unit should include repletion of intravascular volume with large amounts of crystalloid intravenous fluids. Pressors are administered as needed to maintain blood pressure, central venous pressures are monitored, and fluids are administered to maintain a pressure of 8–12 cmH_2O. Bicarbonate and low-dose steroids may be used and good blood glucose control maintained. Tight blood glucose control by administration of insulin doses up to 50 U/h is associated with a reduction in mortality. Recombinant activated protein C (dotrecogin alpha) is a new drug that has been approved for therapy of severe sepsis. Multidisciplinary treatment is essential to obtain good results [7, 10, 66, 67].

Conclusions

Septic complications in genitourinary surgery are a life-threatening scenario that urologists wish to avoid during their practice. To achieve this goal or to minimize the risk of sepsis, a thorough medical history must be performed in order to identify patient risk factors; it is necessary to assess the appropriate time to perform surgery according to the potential infectious sources and to provide correct preoperative prophylaxis and follow-up. Once an infectious complication is suspected, it is imperative to act fast and accurately in a multidisciplinary fashion to avoid the progression of the natural history of sepsis and to provide a better opportunity for recovery.

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CHAPTER 5

Management of Anticoagulation Therapy in Endoscopic and Laparoscopic Urologic Surgery

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Introduction

The benefit of anticoagulants has been shown for a number of cardiovascular disorders, including atrial fibrillation, cardiac stent management, and thromboembolic disorders. While these anticoagulants are necessary, they can pose a difficult and complex problem for both the urologist and patient when elective or nonelective procedures need to be performed. Anticoagulants vary in their mechanism of action, half-life, and bleeding risk. This chapter addresses anticoagulants and the management of patients on anticoagulants for specific urologic disorders and procedures.

In order to adequately understand the mechanism of action of the anticoagulants, a brief review of the hemostasis and coagulation cascade is necessary. Hemostasis requires appropriate function of four key components: platelet activation and aggregation, the clotting cascade, termination of clot formation, and fibrinolysis.

Normal hemostasis

Normal hemostasis requires a physiologic balance between prothrombotic and anticoagulant factors. Vascular injury results in the initiation of clotting and is dependent on three components: the vascular wall, platelets, and the coagulation cascade [1].

The initial step of this process is the formation of a platelet plug. This is completed in three steps: adhesion, aggregation, and the secretion of procoagulant proteins that interact between platelets and endothelial cells, as well as between individual platelets. Von Willibrand's factor, glycoprotein (GP) IIb/IIIa, and GP 1b are all proteins that are involved in the formation and propagation of the platelet plug.

The second important step in thrombosis is the initiation of the coagulation cascade. While a thorough discussion of the coagulation cascade is beyond the scope of this chapter, a brief summary is given (Figure 5.1). The coagulation cascade is a series of steps in which proenzymes are converted to activated enzymes, and the final product is fibrin. The cascade is divided between the extrinsic and intrinsic pathways. At the site of vascular injury, the extrinsic pathway is initiated, beginning with the release of tissue factor from endothelial cells. Tissue factor then complexes with Factor VIIa, which activates Factor Xa, and Factor Va which activates prothrombin to thrombin. Factors Xa and Va represent a final common pathway for both the extrinsic and intrinsic pathways. Thrombin has a positive feedback to the intrinsic pathway, activating Factor XII, and through a series of steps, including activation of Factors XI, IX, and VIII, activate Factor Xa and Va and sustain coagulation.

Many of the proenzymes in the coagulation cascade are dependent upon vitamin K as a cofactor, and therefore antagonists such as warfarin will disrupt the coagulation process. Proteins C and S are vitamin K-dependent enzymes that inactivate Factor Va and VIIIa. Antithrombin (AT) neutralizes many of the enzymes of the clotting cascade, in particular thrombin, Factors IXa, Xa, XIa, and XIIa by forming irreversible complexes.

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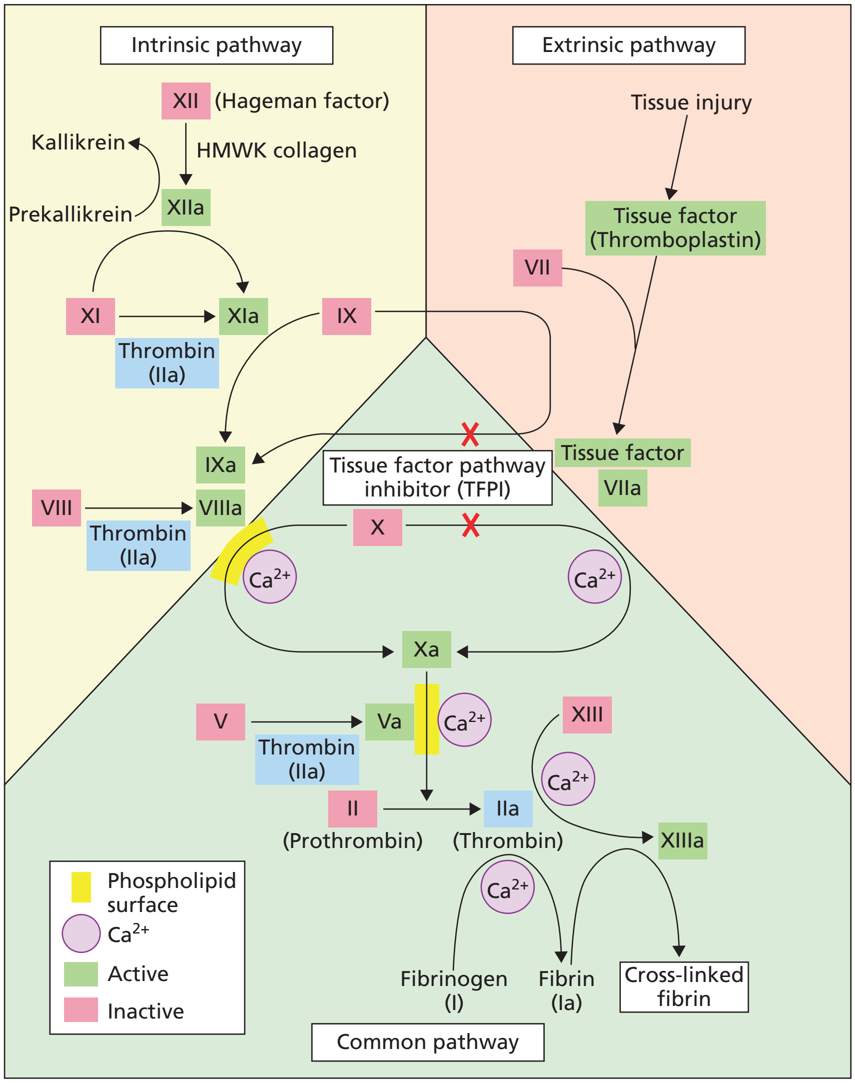
Intrinsic pathway
Extrinsic pathway
XII (Hageman factor)
HMWK collagen
Kallikrein
Prekallikrein
XIIa
Tissue injury
Tissue factor (Thromboplastin)
VII
XI
XIa
IX
Thrombin (IIa)
IXa
Tissue factor pathway inhibitor (TFPI)
Tissue factor
VIIa
VIII
VIIIa
Thrombin (IIa)
X
Ca2+
Ca2+
Xa
V
Va
Ca2+
XIII
Thrombin (IIa)
Ca2+
II
IIa
(Prothrombin)
(Thrombin)
XIIIa
Ca2+
Phospholipid surface
Ca2+
Active
Inactive
Fibrinogen (I)
Fibrin (Ia)
Cross-linked fibrin
Common pathway

Figure 5.1 Coagulation cascade. HMWK, high molecular weight kininogen (From Robbins and Cotran Pathologic Basis of Disease, Professional Edition, 8th ed).

Drug-mediated anticoagulation

Warfarin

Warfarin is a vitamin K-dependent anticoagulant. It achieves its anticoagulation effect by decreasing levels of vitamin K-dependent clotting factors (Factors II, VII, IX, and X) by indirectly inhibiting carboxylation (and thus activation) of newly synthesized clotting factors through the VKORC1 pathway. This pathway causes oxidative reduction of vitamin K, which then allows for carboxylation of clotting factors from their inactive to active form. Therefore, warfarin administration results in the inability to synthesize active vitamin K-dependent clotting factors. The result of this is a delayed effect of antithrombotic activity until pre-existing active clotting factors are expended. Of the vitamin K-dependent clotting factors, prothrombin (Factor II) has the longest half-life (~60 h), which explains the delay in antithrombotic activity after initiation of warfarin therapy.

Careful monitoring of warfarin levels is mandatory as many variables can influence the efficacy of a given dose. These variables include vitamin K stores/intake, medical conditions (liver disease, thyroid disease, infection, fever, heart failure), and medications (quinolones, antifungals, trimethoprim–sulfamethoxazole, amiodarone, rifampin, barbiturates, levothyroxine, metronidazole). Monitoring is performed by a standardized international normalized ratio (INR). Specific target INR ranges have been developed for many underlying medical diseases requiring warfarin therapy.

Heparin

Unfractionated heparin (UFH) is the most common antithrombin (AT) anticoagulant; and is dependent upon binding AT and thrombin together in order to mediate thombolysis. It is the mainstay of bridging therapy as its half-life is short and it is given as a continuous infusion. It can be turned off between 4 and 6 h prior to elective surgery and resumed after surgery at the surgeon's discretion, based on bleeding risk. UFH is favorable in that the dose can be easily titrated.

Low molecular weight heparin (LMWH) has a similar mechanism of action, but due to its smaller size, it is theoretically less effective at binding AT and thrombin together. It can be given as both intravenous and subcutaneous injection, and therefore anticoagulation management can be performed as an outpatient directed by the clinician.

Bridging therapy with either UFH or LMWH is typically started 36 h after the last dose of warfarin. In general, LMWH can be held for 24 h prior to elective surgery [2]. Less than 1% of patients will develop heparin-induced thrombocytopenia (HIT) while on UFH, and even fewer with LMHW. Patients who have a history or HIT or develop a history can be bridged with direct inhibitors of thrombin, which include argatoban and lepirudin.

Antiplatelet-mediated anticoagulation

Aspirin (ASA) and thienopyridines inhibit platelet function. Their mechanisms of action, however, differ. Thienopyridines, the most common of which is clopidogrel, inhibit ADP-dependent platelet activation and aggregation by irreversibly disabling the GP IIb/IIIa ligand between platelets. ASA irreversibly inhibits cyclooxygenase-1 (COX-1), which is typically converted to thromoboxane A_2, also required for platelet aggregation. Platelets are unable to generate new COX-1 and therefore ASA inhibition of platelet aggregation lasts the life of the platelet (7–10 days). Nonsteroidal anti-inflammatory drugs (NSAIDs) reversibly inhibit COX-1 and are therefore weaker anticoagulants.

ASA and thienopyridines are used for the treatment and prevention of cardiovascular diseases. There are a number of guidelines regarding indications for use of these medications for prevention; however, in general, patients using this class of medication for prevention of coronary artery disease are at low risk for complications if the medication is stopped during intervention. In contrast, patients with coronary artery stents may be at risk for stent thrombosis when anticoagulant therapy is stopped [3].

Guidelines

Management of anticoagulation in the perioperative period requires an understanding of the underlying pathologic state requiring anticoagulation, e.g. atrial fibrillation, presence of mechanical heart valve, and risk of thromboembolism. For example, those patients with a history of recurrent venous or pulmonary thromboembolism have a risk of recurrence as high as 15%/year. That incidence increases to as high as 50% in the first 3 months after an initial event [4].

In 2008 the American College of Chest Physicians introduced guidelines regarding management of those patients talking vitamin K antagonists [5, 6]. Patients were stratified according to risk (high, moderate, low) of either arterial or venous thromboembolic event based on the underlying need for anticoagulation (Table 5.1). Those patients with a risk greater than 10%/year of a thromboembolic event were considered high risk.

Bridging therapy with heparin is recommended for all high-risk patients, including those with mitral valve prosthesis, recent transient ischemic attack (TIA), and $CHADS_2$ score of 5 or 6. $CHADS_2$ score is a prediction tool for identifying patients with atrial fibrillation who require anticoagulation. Risk factors such as age older than 75 and congestive heart failure (CHF) are each given a point, with a total possible score of 6 (Table 5.2). Those patients with higher risk scores are more likely to have thromboembolic events [7].

Moderate risk (4–10%/year) patients include those with bileaflet aortic prosthesis with an associated cardiac conditions, $CHADS_2$ score of 3 or 4, active cancer, and venous thromboembolism within the past 3–12 months. Bridging therapy is also recommended for those patients with either LMWH or UFH.

For those patients who are low risk (<4%/year), bridging with low-dose LMWH or interruption of vitamin K antagonist is recommended. These patients include individuals with a $CHADS_2$ score of 0–2, a single venous thromboembolic event more than 12 months ago, or bileaflet aortic valve prosthesis without further comorbidities.

Additionally, withdrawal of warfarin can cause a reflex hypercoaguable state. Great caution should be taken when withdrawing and restarting warfarin therapy in patients with certain conditions with known risk of thromboembolism, including antiphospholipid conditions, and protein C and protein S deficiencies [8].

Controversy still exists regarding the minimum length of treatment of patients after percutaneous coronary intervention (PCI) with platelet inhibitors; this depends on the type of stent placed and the risk of bleeding. Rates of stent thrombosis are generally low, however the risk of thrombotic event after placement of drug-eluting stents is highest in those patients in whom clopidogrel has been discontinued [9].

According to recent guidelines from both the American Heart Association, the American College of Cardiology [10], and the American College of Chest Physicians [5], patients with bare metal stents should continue both ASA and clopidogrel for at least 1 month post PCI, and preferably up to 1 year, and patients with drug-eluding stents should continue ASA and clopidogrel for at least

Table 5.1 Patient risk stratification for perioperative arterial or venous thromboembolism [5] (From Douketis JD, Berger PB, Dunn AS, et al. Chest 2008;133(6 Suppl):299S–339S © American College of Chest Physicians).

Risk stratification	Indication for vitamin K anticoagulation therapy		
	Mechanical heart valve	Atrial fibrillation	Venous thromboembolism (VTE)
High	Any mitral valve prosthesis Older (caged-ball or tilting disc) aortic valve prosthesis Recent (within 6 months) stroke or transient ischemic attack (TIA)	$CHADS_2$ score 5 or 6 Recent (within 3 months) stroke or TIA Rheumatic valvular heart disease	Recent (within 3 months) VTE Severe thrombophilia (e.g. deficiency of protein C, protein S or antithrombin, antiphospholipid antibodies, or multiple abnormalities)
Moderate	Bileaflet aortic valve prosthesis and one of the following: atrial fibrillation, prior stroke or TIA, hypertension, diabetes, congestive heart failure, age >75	$CHADS_2$ score 3 or 4	VTE within the past 3–12 months Nonsevere thrombophilic conditions (e.g., heterozygous factor V Leiden mutation, heterozygous factor II mutation) Recurrent VTE Active cancer (treated within 6 months or palliative)
Low	Bileaflet aortic valve prosthesis without atrial fibrillation and no other risk factors for stroke	$CHADS_2$ score 0–2 (and no prior stroke orTIA)	Single VTE >12 months ago and no other risk factors

Table 5.2 $CHADS_2$ score [7].

	$CHADS_2$ risk stratification	
	Risk factor	Points
C	Congestive heart failure	1
H	Hypertension 140/90 mmHg	1
A	Age >75	1
D	Diabetes mellitus	1
S	Prior stroke or transient ischemic attack	2

12 months, with almost no exceptions. This makes nonelective noncardiac surgery planning complex as those patients with a new diagnosis of cancer may benefit from placement of bare metal stents rather than drug-eluting stents. Discussion of specific cases should be undertaken with the patient's cardiologist in order to devise a specific plan of care for that particular patient.

Urologic procedures

The management of patients on anticoagulation requires a balance of both the risks and benefits of stopping or continuing the anticoagulation. This is typically based on a number of factors, including the risk of bleeding with a particular intervention both intraoperatively and postoperatively, and the risk of thromoboembolic events when not on anticoagulation.

Cystoscopy

In ideal circumstances, cystoscopy, like the majority of endoscopic procedures, should be an atraumatic intervention. While a paucity of data exists regarding the risk of bleeding during surveillance and diagnostic cystoscopic procedures with either flexible or rigid instruments, it is typically unnecessary to stop any form of anticoagulant during routine diagnostic or surveillance cystoscopy. If that procedure has a risk of being combined with an additional cystoscopic or ureteroscopic intervention, then the risk assessment of anticoagulation should be for the more invasive procedure.

Transurethral resection of the prostate

Over the past 15 years many different technologies have evolved for eliminating obstructive prostatic tissue. The gold standard, transurethral resection of the prostate (TURP), has a significant risk of bleeding requiring transfusion in patients without anticoagulation. In that regard, many clinicians recommend stopping all forms of anticoagulation prior to TURP. For those patients on ASA or NSAIDs, these medications should be stopped 1 week prior to the procedure, while patients on warfarin can either be bridged with heparin or have partial cessation of warfarin therapy. This choice is typically dependent upon the reason for warfarin therapy.

Newer technologies, including laser enucleation or vaporization of the prostate and bipolar resection/vaporization, are thought to be more hemostatic than traditional TURP. Sandhu *et al*. reviewed 24 patients on anticoagulation with clopidogrel, ASA, or warfarin, who underwent photoselective vaporization of the prostate (PVP) with a high power KTP laser [11]. Those patients taking warfarin discontinued taking it 2 days preoperatively; those taking other anticoagulants continued their treatment. There was no significant change in serum hematocrit, no need for transfusion, and no significant hematuria or clot retention postoperatively.

Studies evaluating bipolar TURP have found decreased intraoperative blood loss and decrease in change of postoperative hematocrit. Fagerstom *et al*. randomized 202 patients to monopolar versus bipolar TURP and found decreased rates of blood loss with the latter [12]. While this study did not evaluate for the presence or absence of anticoagulation, the results may suggest that bipolar TURP may be a safer procedure if anticoagulation cannot be stopped.

Ureteroscopy/renoscopy

Similar to cystoscopy, diagnositc and surveillance ureteroscopy / renoscopy should be able to be performed with minimal trauma to surrounding tissues. In that regard, patients should be able to tolerate continuation of anticoagulation with minimal risk of bleeding. Similar to cystoscopy, there is a paucity of literature to describe the risk of bleeding during these diagnostic procedures. When combined with either biopsy or stone manipulation, the risk of bleeding may increase. Turna *et al*. compared a series of 37 patients on ASA, clopidogrel, or warfarin who underwent ureteroscopy and laser lithotripsy with matched controls [13]. No difference in stone-free rates, intraoperative or postoperative complications, or hemorrhagic or thromboembolic complications were found. None of the patients receiving anticoagulation required early termination of the procedure due to bleeding. Twenty-five patients with bleeding diathesis, including warfarin use, treated for ureteral or renal stone disease were reviewed by Watterson *et al*. [14]. The overall stone-free rate was reported as 96%. There was one episode of retroperitoneal hemorrhage which required transfusion. This was associated with use of an endoscopic hemorrhoidal ligation (EHL) device.

In conclusion, stone manipulation with ureteroscopy and laser manipulation appears to have similar success in those patients on anticoagulation and those who are not. When performing stone manipulation, EHL devices should be avoided because of the increased risk of bleeding.

Percutaneous lithotripsy

Percutaneous urologic procedures are usually performed for management of renal calculus disease. Due to the invasive nature of the procedure and risk of hemorrhage during needle passage, tract dilation, or nephroscopy, uncorrected coagulopathy is an absolute contradindication for percutaneous nephrolithotomy (PCNL) [15]. In non-anticoagulated patients, intraoperative and perioperative hemorrhage is not uncommon. Transfusion rates of up to 34% have been described. Delayed bleeding occurs in approximately 1% of patients [16].

Kefer *et al*. recently published a series of 27 patients on anticoagulation with clopidogrel, warfarin, or cilostazol [17]. Patients on warfarin were bridged with LMWH and warfarin was resumed on postoperative day 5. Patients on cilostazol and clopidogrel stopped these drugs 10 days prior to surgery and resumed them 7 days postoperatively. The overall stone-free rate was 93%. Two patients had significant bleeding while one had a thromboembolic event.

An alternative to PCNL for large stone burden in patients at high risk for cessation of anticoagulation therapy is staged ureteroscopy with laser lithotripsy, as reported by Ricchiuti *et al.* [18]. Twenty-three patients with an average initial stone burden of 3 cm underwent ureteroscopy with laser lithotripsy. No intraoperative complications were reported. Secondary procedures were required in 43% of patients. Stone-free rates were reported as 73.9%.

PCNL appears to be an effective treatment modality for patients who are on anticoagulation that can be safely withdrawn; however, in high-risk patients, a staged ureteroscopic approach has been shown to be an effective option for management of large stones.

Laparoscopy

A description of the full scope of the physiologic effects of laparoscopy is beyond the scope of this chapter. However, uncontrolled coagulopathy is a contraindication to performing laparoscopic surgery. Guidelines for intervention in a laparoscopic setting are similar to those for open surgery, and temporary cessation of anticoagulation or bridge therapy are the hallmarks of management.

Partial nephrectomy

Kefer *et al*. performed a case control study in 47 patients on long-term anticoagulation with warfarin, clopidogrel, or cilostizol, which was appropriately stopped perioperatively [19]. There was no difference in transfusion rate, but a slightly increased intraoperative blood loss and drop in hematocrit in the patients on anticoagulation. There were five thrombotic events in the anticoagulation group and none in the control group.

Varkarakis *et al*. examined 25 patients on chronic warfarin who underwent radical laparoscopic nephrectomy after bridging with heparin and reported no evidence of increased risk of intraoperative bleeding [20]. However, there was a higher incidence of postoperative bleeding as well as transfusion rate. There were no thromboembolic complications in the anticoagulation group.

With appropriate management of the anticoagulation, both radical and partial laparoscopic nephrectomy can be performed safely on patients who require long-term anticoagulation. Currently, there is no strong evidence to support an increased risk of postoperative bleeding or need for transfusion.

Deep vein thrombosis prophylaxis

In 2008 the American Urological Association (AUA) published guidelines regarding deep vein thrombosis (DVT) prophylaxis for urologic procedures [21]. Defining the risk of DVT is critical in determining appropriate prophylaxis. Factors predisposing patients to DVT include immobility, trauma, malignancy, previous cancer therapy, past history of DVT, increasing age, pregnancy, estrogen therapy, obesity, smoking, venous varicosities, central venous catheterization, myeloproliferative disorders, nephrotic syndrome, and inherited or acquired thrombophilia. Patients should be stratified into low-, intermediate-, high-, and highest-risk categories based upon age and comorbidities (Table 5.3) [21]. In patients undergoing transurethral surgery who are at increased risk for DVT, graduated compression stockings (GCS) and intermittent pneumatic compression (IPC) may be recommended, with a decrease in the incidence of postoperative pulmonary thromboemolism from 0.55% to 0.45% with use of GCS. It is unclear as to the benefit of heparin prophylaxis in this cohort of patients given the conflicting results regarding increased bleeding risk. All patients undergoing laparoscopy or robotic surgery should wear intermittent compression devices as recommended by the AUA guideline panel [21]. Due to the lack of randomized controlled trials for this patient population, there is no consensus regarding the use of pharmacologic DVT prophylaxis. However, patients falling into the high-risk and highest-risk categories should be considered for pharmacologic prophylaxis.

Table 5.3 Patient risk stratification for DVT prophylaxis for urologic procedures (from AUA guidelines for DVT prophylaxis [21]).

Low risk	Minor surgery in patients <40 years with no additional risk factors
Moderate risk	Minor surgery in patients with additional risk factors
	Surgery in patients aged 40–60 years with no additional risk factors
High risk	Surgery in patients >60 years
	Surgery in patients aged 40–60 years with additional risk factors (prior venous thromboembolism, cancer, hypercoagulable state)
Highest risk	Surgery in patients with multiple risk factors (age >40 years, cancer, prior venous thromboembolism)

Conclusions

The management of anticoagulation for endoscopic and laparoscopic urologic procedures is a complex challenge for the clinician. Individual treatment plans for patients need to be developed based on risk stratification for thromboembolic events, the type of anticoagulant, reason for therapy, and the invasiveness and character of surgery. In all instances, risk stratification of the patient is critical in determining the optimal treatment modality. In some circumstances, anticoagulation may be stopped altogether; in others, patients can proceed to surgery while on anticoagulant therapy or bridging therapy with heparin may be necessary. Urologists must therefore be aware of the intricacies of these issues and be prepared to discuss them with their patients to provide optimal care.

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SECTION 2
Percutaneous Renal Surgery

CHAPTER 6

Surgical Anatomy of the Kidney in the Prone, Oblique, and Supine Positions

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General anatomy

The kidneys are paired organs lying retroperitoneally on the posterior abdominal wall. Each kidney has a characteristic shape, with a superior and an inferior pole, a convex border placed laterally, and a concave medial border. The medial border has a marked depression, the hilum, containing the renal vessels and renal pelvis.

Renal morphometry

In adults, the left kidney is larger than the right, and this agrees withmorphometric findings in fetal kidneys [1]. The right kidney has a mean length of 10.97 cm and 3.21 cm mean thickness at the hilum, in comparison to 11.21 cm and 3.37 cm, respectively, for the left kidney [2].

An interesting finding is that the superior pole has a greater width (mean, 6.48 cm) than the inferior pole (mean, 5.39 cm). Also, we have found a statistically significant correlation between kidney length and an individual's stature [2].

Position of the kidneys

Because the kidneys lie on the posterior abdominal wall, against the psoas major muscles, their longitudinal axis parallels the oblique course of the psoas (Figure 6.1). Moreover, since the psoas major muscle has a cone shape, the kidneys also are dorsally inclined on the longitudinal axis. Therefore, the superior poles are more medial and more posterior than the inferior poles (Figure 6.1). Also, because the hilar region is rotated anteriorly on the psoas muscle, the lateral borders of both kidneys are posteriorly positioned. This means the kidneys are angled 30–50° behind the frontal (coronal) plane (Figure 6.2) [3].

Perirenal coverings

The kidney surface is enclosed in a continuous covering of fibrous tissue, the renal capsule ("true renal capsule"). Each kidney within its capsule is surrounded by a mass of adipose tissue, lying between the peritoneum and the posterior abdominal wall (Figures 6.2 and 6.3). This perirenal fat is enclosed by the renal fascia (the so-called fibrous renal fascia of Gerota). The renal fascia is enclosed anteriorly and posteriorly by another layer of adipose tissue, the pararenal fat, which varies in thickness (Figure 6.3).

The renal fascia is made up of a posterior layer (a well defined and strong structure) and an anterior layer (a more delicate structure, which tends to adhere to the peritoneum) (Figures 6.2 and 6.3). The anterior and posterior layers of the renal fascia (fascia of Gerota) subdivide the retroperitoneal space into three potential compartments: (1) the posterior pararenal space, which contains only fat; (2) the intermediate perirenal space, which contains the suprarenal glands, kidneys, and proximal ureters, together with the perirenal fat; and (3) the anterior pararenal space, which unlike the posterior and intermediate spaces, extends across the midline from one side of the abdomen to the other. This latter space contains the ascending and descending colon, the duodenal loop, and the pancreas [3] (Figure 6.4).

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Inferiorly, the layers of the renal fascia end weakly fused around the ureter (Figures 6.3 and 6.5). Superiorly, the two layers of the renal fascia fuse above the suprarenal gland and end fused with the infradiaphragmatic fascia (Figure 6.5). An additional fascial layer separates the suprarenal gland from the kidney (Figure 6.5). Laterally, the two layers of the renal fascia fuse behind the ascending and descending colons. Medially, the posterior fascial layer is fused with the fascia of the spine muscles. The anterior fascial layer merges into the connective tissue of the great vessels (aorta and inferior vena cava) (Figures 6.2 and 6.4).

These anatomic descriptions of the renal fascia show that the right and left perirenal spaces are potentially separated and, therefore, it is exceptional that a complication of an endourologic procedure, e.g. hematoma, urinoma, or perirenal abscess, involves the contralateral perirenal space [3].

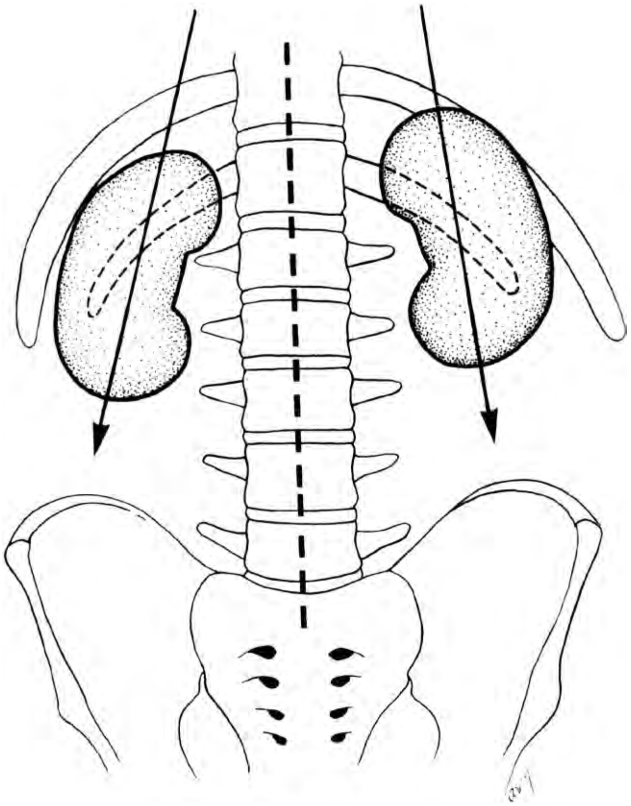

Figure 6.1 Schematic of an anterior view of the kidneys in relation to the skeleton showing that the longitudinal axes of the kidneys are oblique (arrows), with the superior poles more medial than the inferior poles. The dashed lines mark the longitudinal axis of the body. It can also be seen that usually the posterior surface of the right kidney is crossed by the 12th rib and the left kidney by the 11th and 12th ribs.

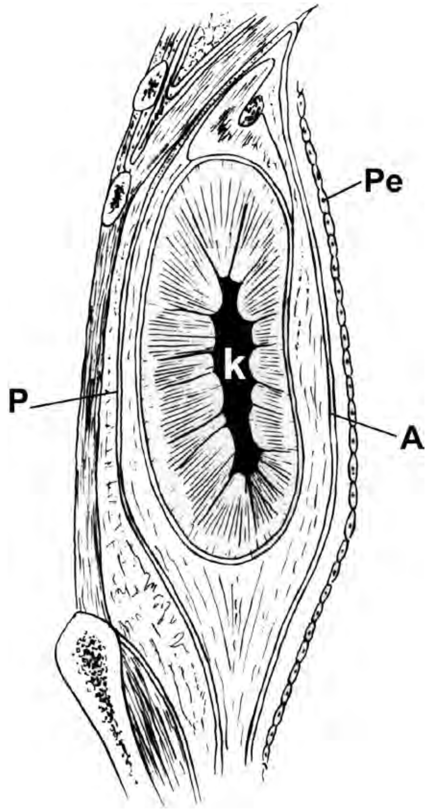

Figure 6.3 Schematic of a lateral view of a longitudinal section through the retroperitoneum showing the posterior (P) and anterior (A) layers of the renal fascia. Pe, peritoneum; K, kidney.

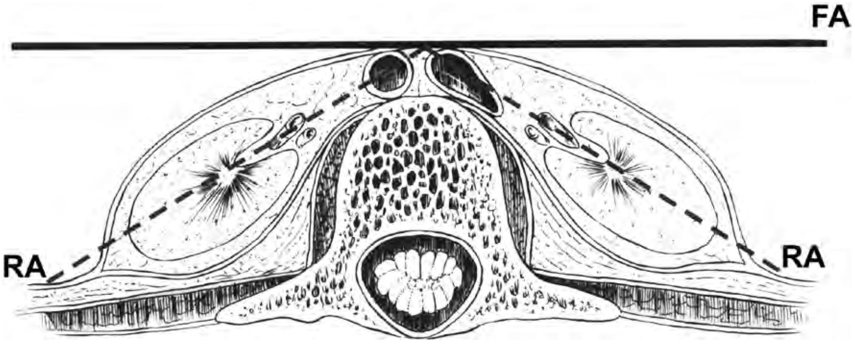

Figure 6.2 Schematic of a superior view of a transverse section of the kidneys at the level of the second lumbar vertebra showing that the kidneys are angled 30–50° behind the frontal (coronal) plane of the body (FA). RA, renal frontal (coronal) axis.

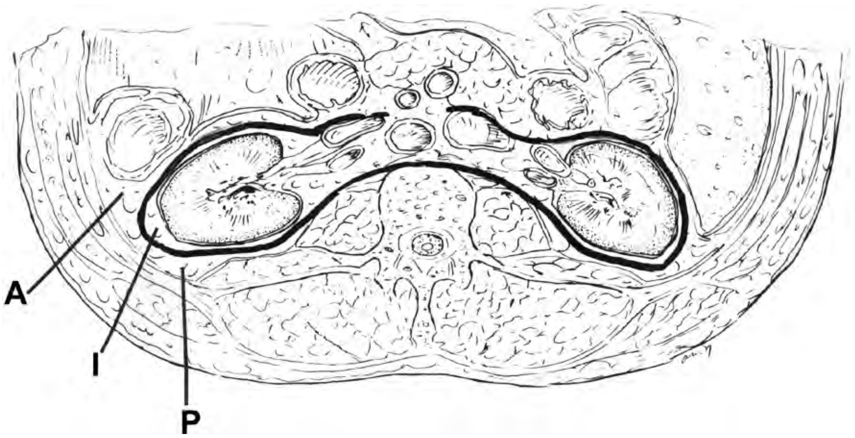

Figure 6.4 Schematic of a superior view of a transverse section of the kidneys at the level of the second lumbar vertebra showing the three compartments of the retroperitoneal space. P, posterior pararenal space, which contains only fat; I, intermediate perirenal space, which contains the suprarenal glands, kidneys, and proximal ureters, together with the perirenal fat; and A, anterior pararenal space, which unlike the posterior and intermediate spaces, extends across the midline from one side of the abdomen to the other, and contains the ascending and descending colons, duodenal loop, and pancreas.

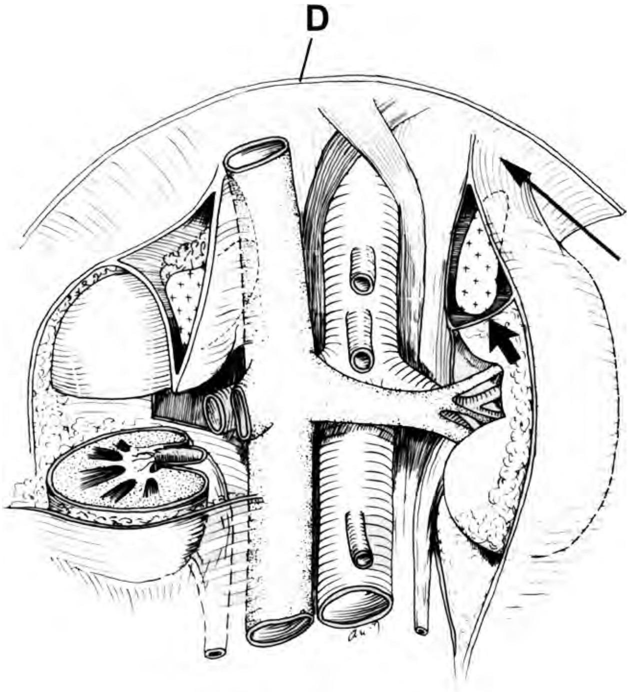

Figure 6.5 Schematic of an anterior view of the renal fascia (Gerotas' fascia) and kidneys. This shows that the two layers of the renal fascia fuse above the suprarenal gland and end fused with the infradiaphragmatic fascia (long arrow). Note a dependence of the fascia separating the suprarenal gland from the kidney (short arrow). D, diaphragm muscle.

Relationship of kidneys to the diaphragm, ribs, and pleura

The kidneys lie on the psoas and quadratus lumborum muscles. Usually, the left kidney is higher than the right kidney, with the posterior surface of the right kidney crossed by the 12th rib and the left kidney crossed by the 11th and 12th ribs (Figure 6.1). The posterior surface of the diaphragm attaches to the extremities of the 11th and 12th ribs (Figure 6.6). Close to the spine, the diaphragm is attached over the posterior abdominal muscles, and forms the medial and lateral arcuate ligaments on each side (Figure 6.6). In this way, the posterior aspect of the diaphragm (posterior leaves) arches in a dome above the superior pole of the kidneys, on each side. Therefore, when performing an intrarenal access by puncture, the endourologist may consider that the diaphragm is traversed by all intercostal punctures, and possibly by some punctures below the 12th rib (Figure 6.7). Also, it can be expected that the pleura is transversed without symptoms in most intercostal approaches [4].

Generally, the posterior reflection of the pleura extends inferiorly to the 12th rib; nevertheless, the lowermost lung edge lies above the 11th rib (at the 10th intercostal space) (Figure 6.7). Regardless of the degree of respiration (mid or full expiration), the risk of injury to the lung from a 10th intercostal percutaneous approach to the kidney is prohibitive [4]. Any intercostal puncture should be made in the lower half of the intercostal space, in order to avoid injury to the intercostal vessels above.

Relationship of kidneys to the liver and spleen

The liver on the right side and the spleen on the left may be posterolaterally positioned at the level of the suprahilar region of the kidney, because at this point these organs have their largest dimensions (Figure 6.8). Therefore, it should be remembered that a kidney puncture performed high in the abdomen will allow little space for the needle entrance [4]. If the intrarenal puncture is performed when the patient is in mid or full inspiration, the risk of injury to the liver and spleen is increased [4]. This knowledge is particularly important in patients with hepatomegaly or splenomegaly, in whom a computed tomography (CT) scan should be performed before puncturing the kidney.

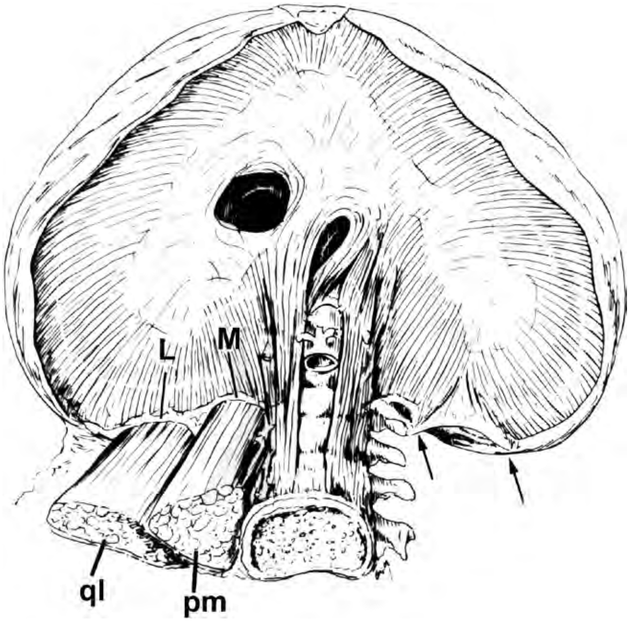

Figure 6.6 Schematic of an inferior view of the diaphragmatic dome. The arrows point to the diaphragmatic attachments to the extremities of the 11th and 12th ribs. M, medial arcuate ligament; L, lateral arcuate ligament; ql, quadratus lumborum muscle; pm, psoas muscle.

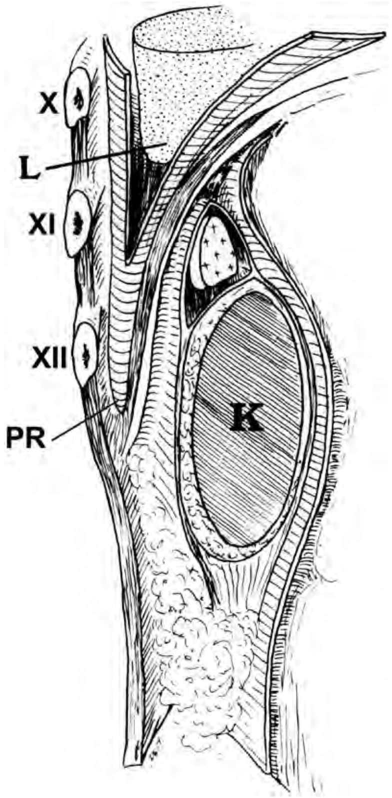

Figure 6.7 Schematic of a lateral view of the kidney and its relationships with the diaphragm, ribs, pleura, and lung. PR, posterior reflection of the pleura, L, lower edge of the lung; K, kidney; X, 10th rib; XI, 11th rib; XII 12th rib.

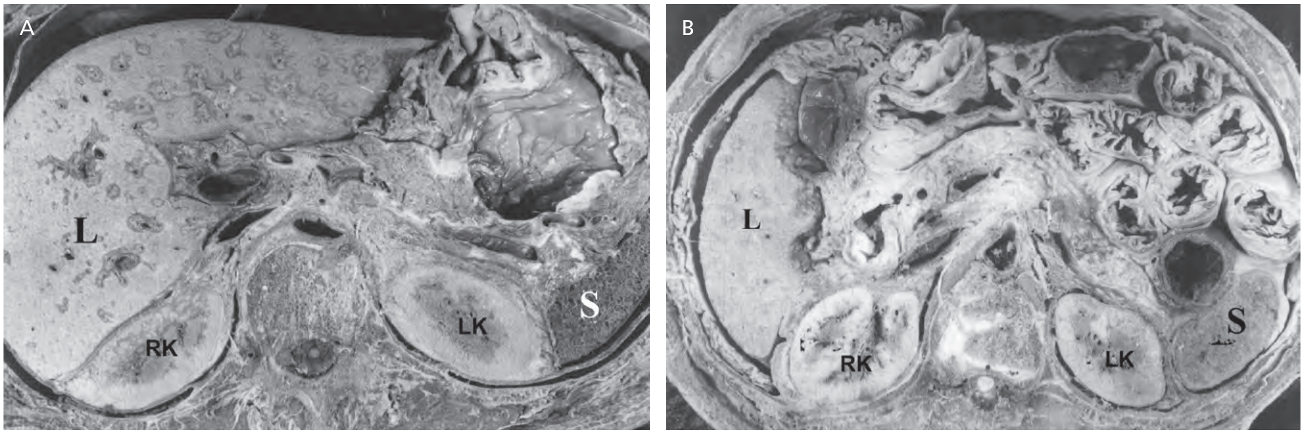

Figure 6.8 (A) Inferior view of a transverse section through a cooled cadaver at the level of the suprahilar region of the kidney. This shows that the liver (L) and spleen (S) are posterolaterally positioned in relation to the right (RK) and left (LK) kidneys. (B) Similar section to A at the level of the infrahilar region. This shows that inferiorly the liver (L) and spleen (S) are more laterally positioned in relation to the right (RK) and left (LK) kidneys.

Relationship of kidneys to the ascending and descending colons

The ascending colon runs from the ileocolic valve to the right colic flexure (hepatic flexure), where it passes into the transverse colon. The hepatic colic flexure (hepatic angle) lies anteriorly to the inferior portion of the right kidney. The descending colon extends inferiorly from the left colic flexure (splenic flexure) to the level of the iliac crest. The left colic flexure lies anterolateral to the left kidney.

It is important to consider the position of the retroperitoneal ascending and descending colons. Occasionally, in

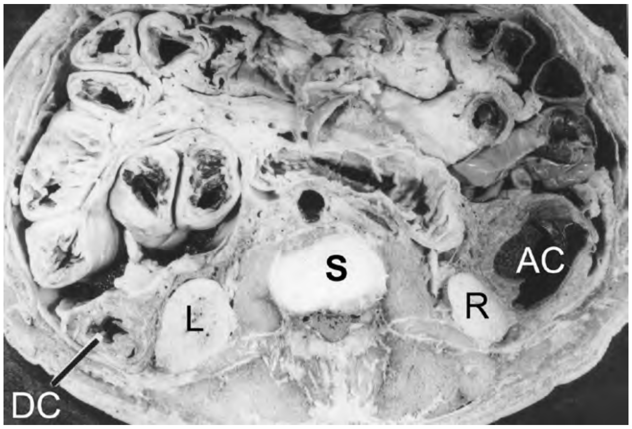

Figure 6.9 Superior view of a transverse section through a cooled cadaver at the level of the inferior poles of the kidney. This shows the ascending (AC) and descending (DC) colons lying in a posterolateral position in relation to the right (R) and left (L) kidneys. S, spine.

the course of a routine abdominal CT scan, the retroperitoneal colon has been observed to lie in a posterolateral or even a retrorenal position [5], and in these cases, there is a great risk of kidney injury with the intrarenal percutaneous approach. A retrorenal colon is more common in the area of the inferior poles of the kidneys (Figure. 6.9). It Retrorenal colon was found on CT scan in 1.9% of patients in the supine position, but 10% when the prone position (the more commonly adopted position for percutaneous access to the kidney) was assumed [5]. Therefore, with the patient in the prone position and before any invasive percutaneous renal procedure, retrorenal colon should be looked for, especially around the inferior poles of the kidney, using fluoroscopy [5].

Intrarenal vessels

Intrarenal arteries

Generally, the main renal artery divides into an anterior and a posterior branch after giving off the inferior suprarenal artery. Whereas the posterior branch (retropelvic artery) proceeds as the posterior segmental artery to supply the homonymous segment without further significant branching, the anterior branch of the renal artery provides three or four segmental arteries. The segmental arteries divide before entering the renal parenchyma into the interlobar arteries (infundibular arteries), which progress adjacent to the calyceal infundibula and the minor calyces, entering the renal columns between the renal pyramids (Figures 6.10 and 6.11) [6]. As the interlobar arteries progress, near the base of the pyramids, they give origin (usually by dichotomous division) to the arcuate arteries (Figures 6.10 and 6.11). The arcuate arteries give off the interlobular arteries, which run to the periphery, giving off the afferent arterioles of the glomeruli (Figure 6.11) [6].

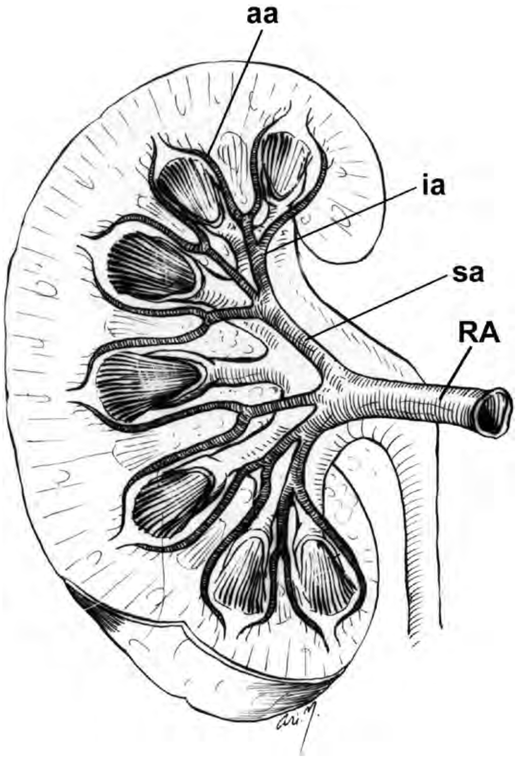

Figure 6.10 Schematic of an anterior view of a right kidney. This shows the branching of the renal arteries and their official nomenclature according to kidney region. RA, renal artery; sa, segmental artery; ia, interlobar (infundibular) artery; aa, arcuate artery.

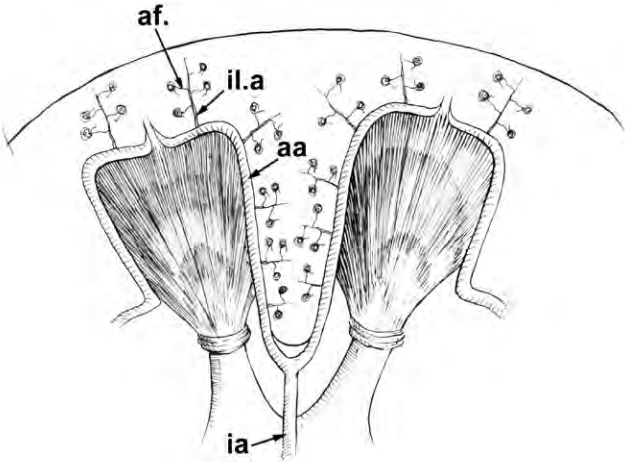

Figure 6.11 Schematic of two adjacent pyramids and minor calyces. This shows the renal vasculature from the level of the interlobar arteries to the glomerular level. ia, interlobar (infundibular artery); aa, arcuate artery; il.,, interlobular artery; af., afferent arteriole of the glomerulus.

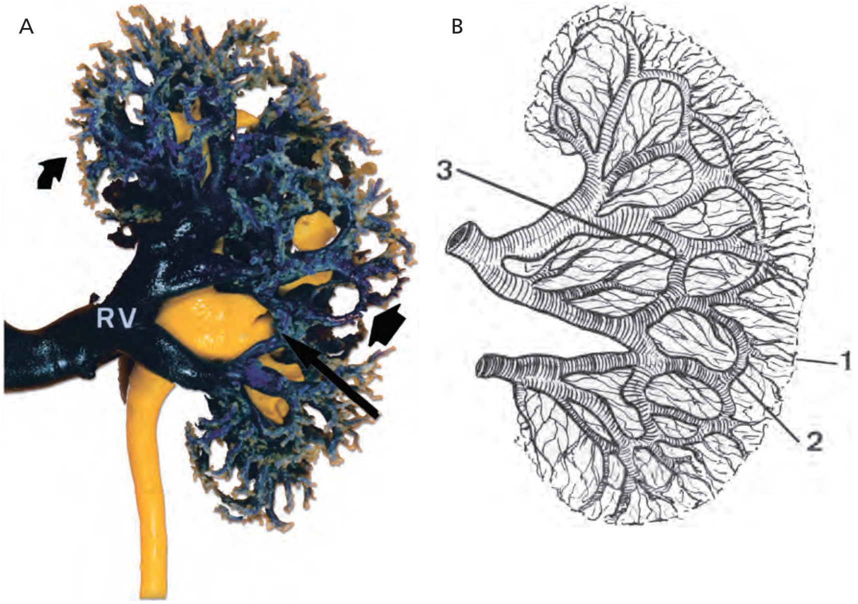

Figure 6.12 (A) Anterior view of a left kidney endocast of the pelviocalyceal system together with the venous vascular tree. This shows the three systems of longitudinal anastomotic arcades; from lateral (periphery) to medial (hilar): stellate veins (curved arrow), arcuate veins (short arrow), and interlobar veins (long arrow). RV, renal vein. (B) Schematic showing the three orders of arcades: 1, first order arcade; 2, second order arcade; 3, third order arcade.

Intrarenal veins

The intrarenal veins, unlike the arteries, do not have a segmental model. Moreover, in contrast to the arteries, there is free circulation throughout the venous system, with ample anastomoses between the veins. These anastomoses, therefore, prevent parenchymal congestion and ischemia in case of venous injury [7].

The small veins of the cortex, called stellate veins, drain into the interlobular veins that form a series of arches (Figure 6.12). Within the kidney substance, these arches are arranged in arcades, which lie mainly in the longitudinal axis. There are usually three systems of longitudinal anastomotic arcades and the anastomoses occur at different levels: between the stellate veins (more peripherally), between the arcuate veins (at the base of the pyramids), and between the interlobar (infundibular) veins (close to the renal sinus) (Figure 6.12). We have named these anastomoses as first order, second order, and third order, from periphery to center [7]. In early studies, we found three trunks (53.8%) and two trunks (28.8%) joining each other to form the main renal vein. Less frequently, we found four trunks (15.4%) and five trunks (1.9%) [7].

A detailed description of the kidney collecting system (the pelviocalyceal system), as well as the anatomic relationships between the intrarenal arteries and veins with the kidney collecting system, which are of utmost importance for endourology, is given below.

Pelvicocalyceal system: endourologic implications

Anatomic classification

Recent advances in endourology have revived interest in collecting system anatomy, since a full understanding of such anatomy is necessary to perform reliable endourologic procedures as well as uroradiologic analysis [8–10]. We have proposed a pelviocalyceal classification, including all morphologic types of collecting systems, which we believe is helpful for standardizing patients and procedures [9]. This classification was derived from the analysis of 140 three-dimensional (3D) polyester resin corrosion endocasts of the pelviocalyceal system (Figure 6.13), obtained from 70 fresh cadavers according to a technique described previously [8].

Basic intrarenal anatomy

The renal parenchyma basically consists of two kinds of tissue, the cortical tissue and medullar tissue. On a longitudinal section (Figure 6.14), the cortex forms the external layer of renal parenchyma. The renal medulla is formed by several inverted cones, surrounded by a layer of cortical tissue on all sides (except at the apices). As in longitudinal sections, a cone assumes the shape of a pyramid (Figure 6.14) and the established term for the medullar tissue is renal pyramid; the apex of this pyramid is termed the renal papilla. The layers of cortical tissue between adjacent pyramids are termed renal columns (cortical columns of Bertin; Figure 6.14) [8, 10].

The cortical tissue is made up of the glomeruli with proximal and distal convoluted tubules. The renal pyramids are made up of loops of Henle and collecting ducts; these ducts join to form the papillary ducts (about 20), which open at the papillary surface (area cribosa; Figure 6.15) and drain urine into the collecting system (into the fornix of a minor calyx).

A minor calyx is defined as the calyx that is in immediate apposition to a papilla (Figures 6.14 and 6.15). The renal minor calyces drain the renal papillae and range

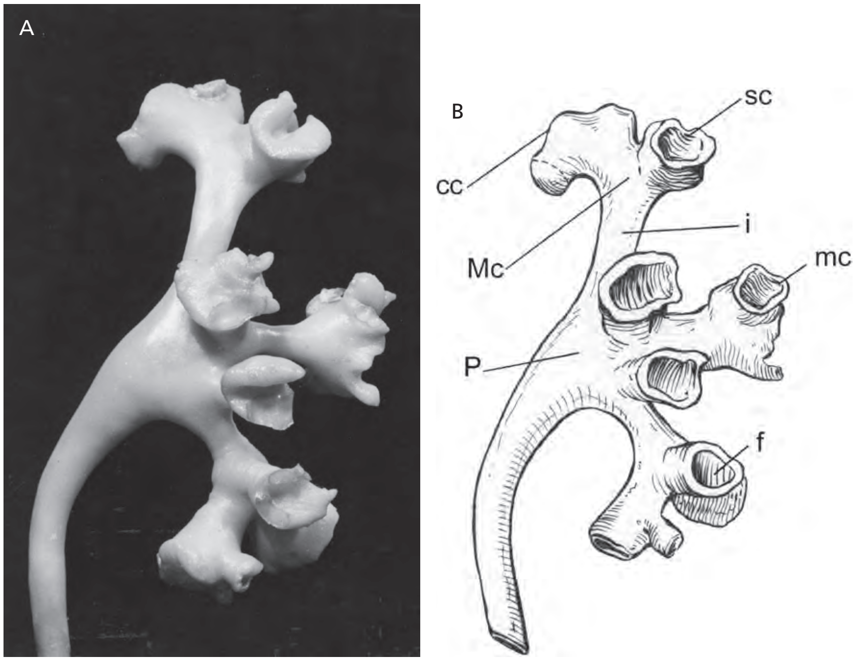

Figure 6.13 (A) Anterior view of a pelviocalyceal endocast from a left kidney, obtained according to the injection–corrosion technique. (B) Schematic of the endocast shown in A. This shows the essential elements of the kidney collecting system. cc, compound calyx; sc, single calyx; mc, minor calyx; Mc, major calyx; f, calyceal fornix; i, infundibulum; P, renal pelvis (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

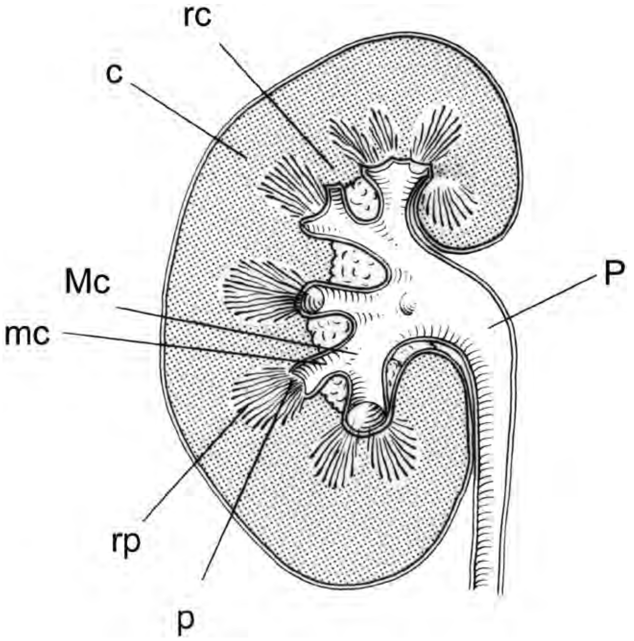

Figure 6.14 Schematic of a longitudinal section of the kidney. This shows the intrarenal structures. c, renal cortex; rc, renal column (cortical column of Bertin); rp, renal pyramid; p, renal papilla; mc, minor calyx; Mc, major calyx; P, renal pelvis (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

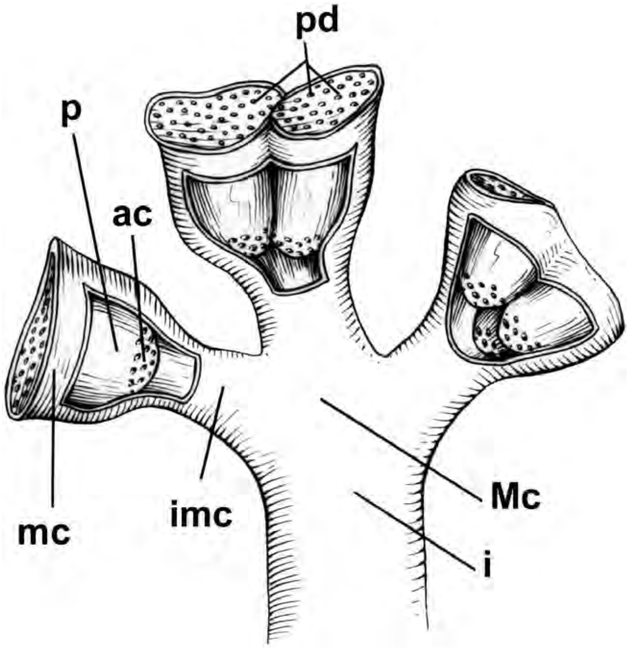

Figure 6.15 Schematic representation of the possible minor calyx (mc) arrangements. A single mc drains only one papilla and a compound mc drains two or three papillae. p, renal papilla; pd, papillary ducts; ac, area cribosa; Mc, major calyx; imc, infundibulum of a mc (calyceal neck); i, infundibulum (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

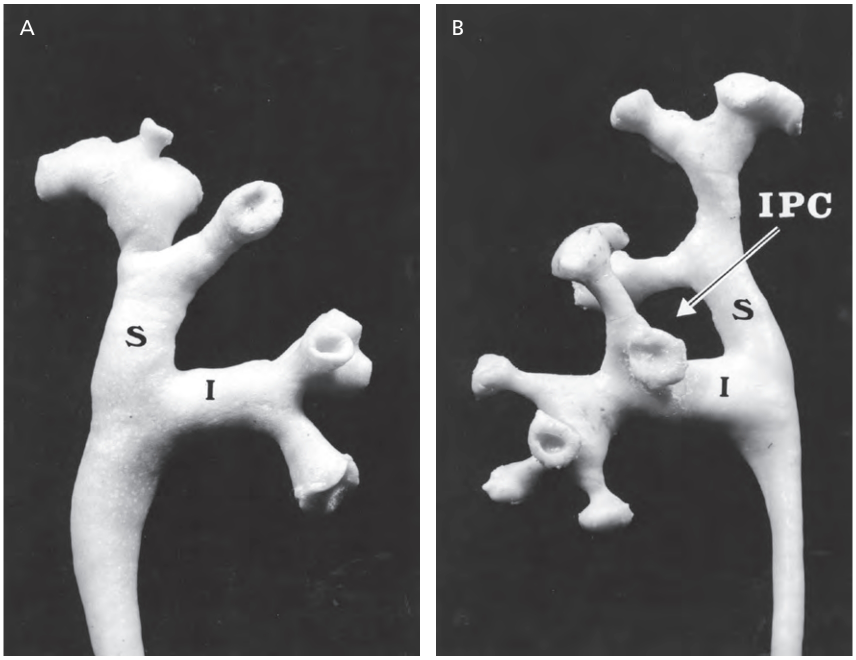

Figure 6.16 View of the two morphologic types of pelviocalyceal systems that compose Group A. (A) Type A-I: anterior view of a left pelviocalyceal endocast shows the kidney midzone drained by calyces dependent on the superior (S) and inferior (I) calyceal groups. (B) Type A-II: anterior view of a right pelviocalyceal cast shows the kidney midzone drained by crossed calyces, dependent simultaneously on the superior (S) and inferior (I) calyceal group. This endocast shows the interpelviocalyceal space (IPC) (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

in number from 5 to 14 (mean, 8); we have found 70% of kidneys to have 7–9 minor calyces [8]. A minor calyx may be single (drains one papilla) or compound (drains two or three papillae) (Figures 6.13 and 6.15). The polar calyces are often compound, markedly in the superior pole (Figure 6.13). The minor calyces may drain straight into an infundibulum or join to form major calyces, which subsequently will drain into an infundibulum (Figures 6.13 and 6.15). Finally, the infundibula, which are considered the primary divisions of the pelviocalyceal system, drain into the renal pelvis.

Classification of the pelviocalyceal system

The analysis of 140 endocasts led us to a division into two major groups (with two intermediate varieties in each major group). This division was based on superior pole, inferior pole, and kidney midzone (hilar) calyceal drainage.

Group A is composed of pelviocalyceal systems that have two major calyceal groups (superior and inferior) as a primary division of the renal pelvis and a midzone calyceal drainage dependent on these two major groups (62.2%) (Figure 6.16). Group A includes two different types of pelviocalyceal system:

- Type A-I (45%). The kidney midzone is drained by minor calyces that are dependent on the superior and/or inferior calyceal groups (Figure 6.16A).
- Type A-II (17.2%). The kidney midzone is drained simultaneously by crossed calyces, one draining into the superior calyceal group and the other draining into the inferior calyceal group (Figure 6.16B). When we analyzed the endocasts with crossed calyces in the kidney midzone, we observed that the crossed calyces (laterally) and the renal pelvis (medially) bound a region (space) that we designated the "interpelviocalyceal" (IPC) region (space) (Figure 6.16B).

Group B is composed of pelviocalyceal systems with kidney midzone (hilar) calyceal drainage independent of both the superior and inferior calyceal groups (37.8%) (Figure 6.17). This group also includes two different types of pelviocalyceal system:

- Type B-I (21.4%). The kidney midzone is drained by a major calyceal group, independent of both the superior and the inferior groups (Figure 6.17A).
- Type B-II (16.4%). The kidney midzone is drained by minor calyces (one to four) entering directly into the renal pelvis (Figure 6.17B). Such calyces are independent of both the superior and inferior calyceal groups.

The kidney collecting system is very variable and is not symmetrical. We found pelviocalyceal systems with morphologic bilateral symmetry in the same individual in only 37.1% of the cases (26 pairs of kidneys).

Although our pelviocalyceal classification includes all morphologic types of calyces and renal pelvices, in performing endourologic procedures it is important to be aware that the collecting system anatomy is very variable. The endocast in Figure 6.18A, for example, reveals a very long and thin superior calyceal infundibulum;

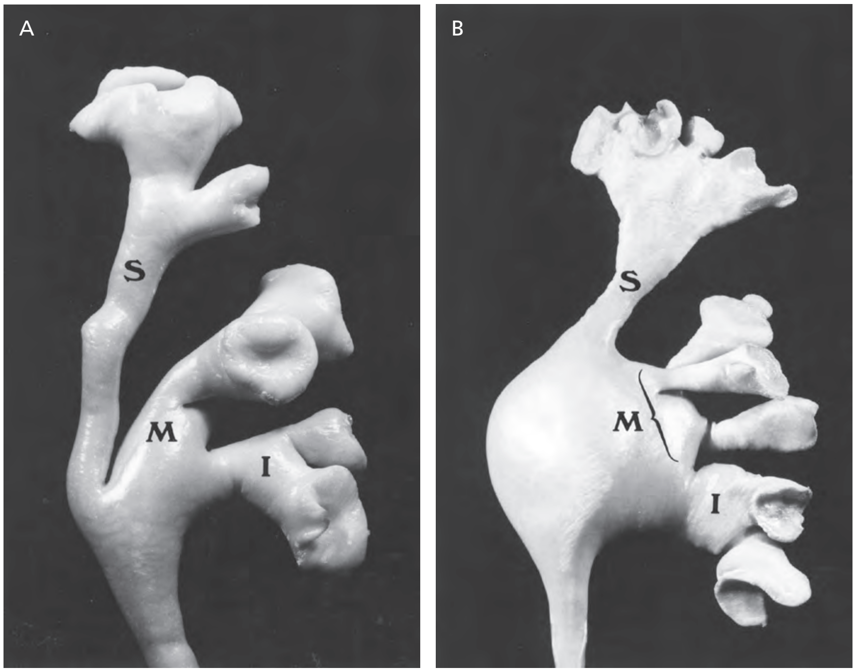

Figure 6.17 View of the two morphologic types of pelviocalyceal systems that compose Group B. (A) Type B-I: anterior view of a left pelviocalyceal endocast shows the kidney midzone drained by a hilar major calyx (M), independently of the superior (S) and inferior (I) major calyces. (B) Type B-II: anterior view of a left pelviocalyceal endocast shows the kidney midzone drained by minor calyces (M) entering directly into the renal pelvis, independently of both the superior (S) and inferior (I) calyceal groups (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

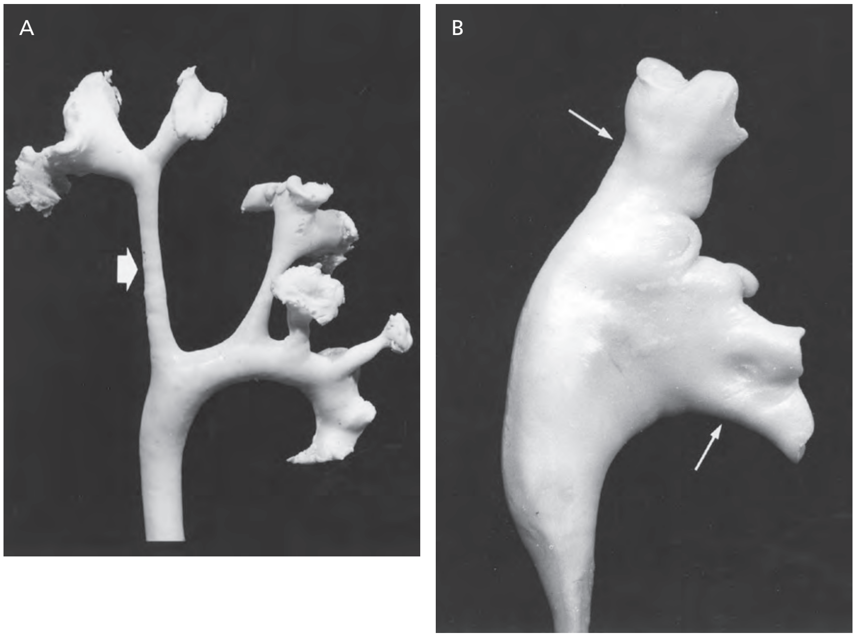

Figure 6.18 Anterior view of two left pelviocalyceal endocasts, one showing a long and thin superior calyceal infundibulum (arrow) (A) and the other a short and thick superior and inferior calyceal infundibula (arrows) (B) (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

this anatomic formation will certainly cause difficulties in the introduction and manipulation of a nephroscope into the superior pole collecting system. The endocast in Figure 6.18B shows just the opposite aspect (both superior and inferior calyceal infundibula are short and thick); this anatomic formation will certainly make it easier to introduce and manipulate a nephroscope within the superior and inferior collecting systems.

Comparative analysis between standard pyelograms and the corresponding three-dimensional collecting system endocasts

Since standard excretory urograms [intravenous pyelograms (IVPs)] show the collecting system in only one plane, it is extremely difficult for the practitioner to visualize and imagine this system in three dimensions.

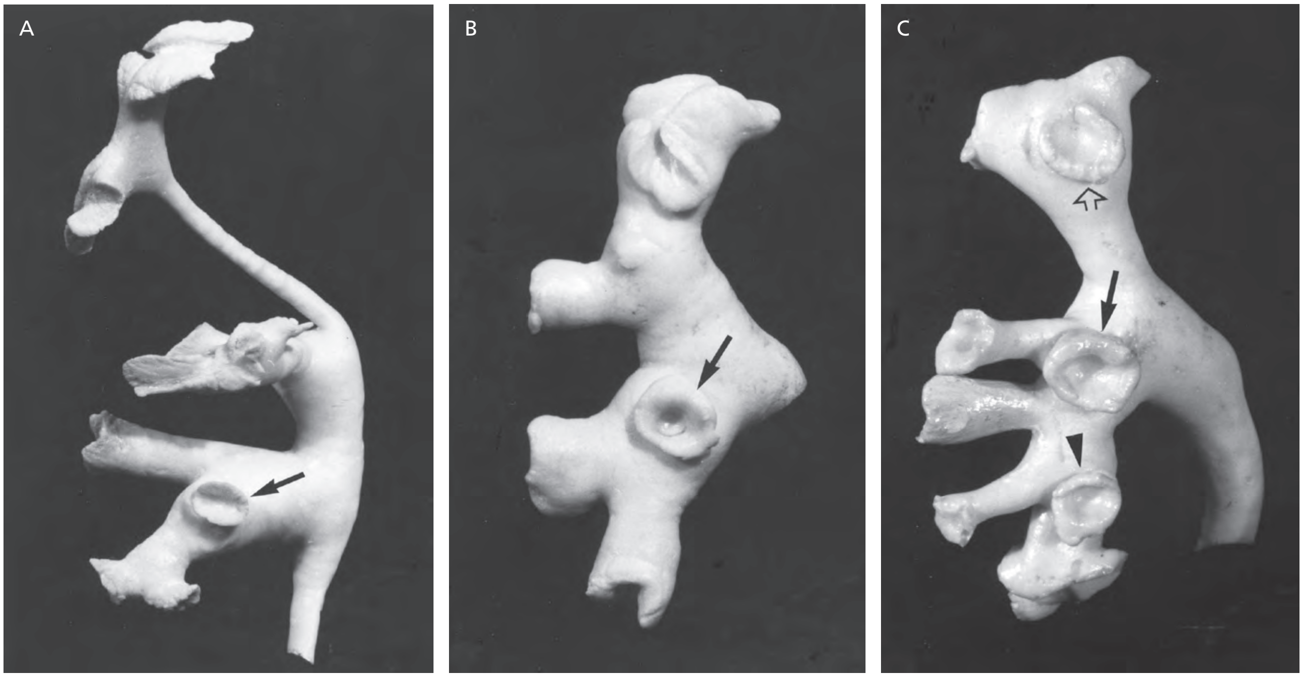

Figure 6.19 Anterior views of a right pelviocalyceal endocast showing (A) a perpendicular minor calyx draining into the inferior calyceal group (arrow); (B) into the inferior calyceal group (arrow), very close to the renal pelvis; and (C) into the renal pelvis (arrow). This latter endocast also shows a perpendicular minor calyx draining into the superior calyceal group (open arrow) and a perpendicular minor calyx draining into the inferior calyceal group (arrowhead) (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

A full understanding of pelviocalyceal anatomy is a prerequisite for successful endourologic interventions in the upper urinary tract, as well as for interpreting IVPs and other imaging examinations.

To assist endourologists in forming a mental image of the collecting system in three dimensions and learning the exact spatial position of the calyces, before obtaining the pelviocalyceal system endocast, iodinated contrast was injected into the ureter of 40 of our cases to opacify the collecting system in order to obtain a pyelogram. After radiography, the contrast was removed and the collecting system was filled with a polyester resin to obtain a 3D endocast. These 40 kidneys enabled a comparative study between the radiographic images and their corresponding 3D endocasts. This identified some remarkable anatomic aspects of the kidney collecting system that need to be considered during endourologic procedures.

Presence of perpendicular minor calyces

In 11.4% of the endocasts (16 of 140) we found a perpendicular minor calyx draining directly into the renal pelvis or into a major calyx (Figure 6.19). The minor calyces perpendicular to the surface of the collecting system, which are seen in the endocasts, can be superimposed on other structures, which means their visualization radiographically can be difficult (Figure 6.20). Stones in such minor calyces viewed on standard anteroposterior radiographic images can appear as if they were placed in the pelvis or a major calyx. Thus, this anatomic detail must be considered in cases of stones that do not alter renal function and can appear as if they are in the renal pelvis or a major calyx. In this situation, a complementary radiologic study with lateral and oblique films must be performed to determine accurately the position and extent of the stones [11, 12].

When a stone is located in a perpendicular minor calyx (Figure 6.19), its removal presents additional difficulties for both extracorporeal shock-wave lithotripsy (ESWL) and percutaneous nephrolithotripsy (PCNL). Patients with stones in such calyces are not good candidates for ESWL because these calyces invariably present narrow infundibula (<4 mm in diameter); therefore, discharge of the disintegrated stone fragments will be difficult [13, 14]. Regarding percutaneous removal, direct access into the calyx containing the stone is easy; nevertheless, it involves a puncture without consideration of the arterial and venous anatomic relationships to the collecting system, which carries a high risk of injuring a vascular structure [12]. Therefore, in cases of stone in such calyces, safe access, techniques, and instruments should be used.

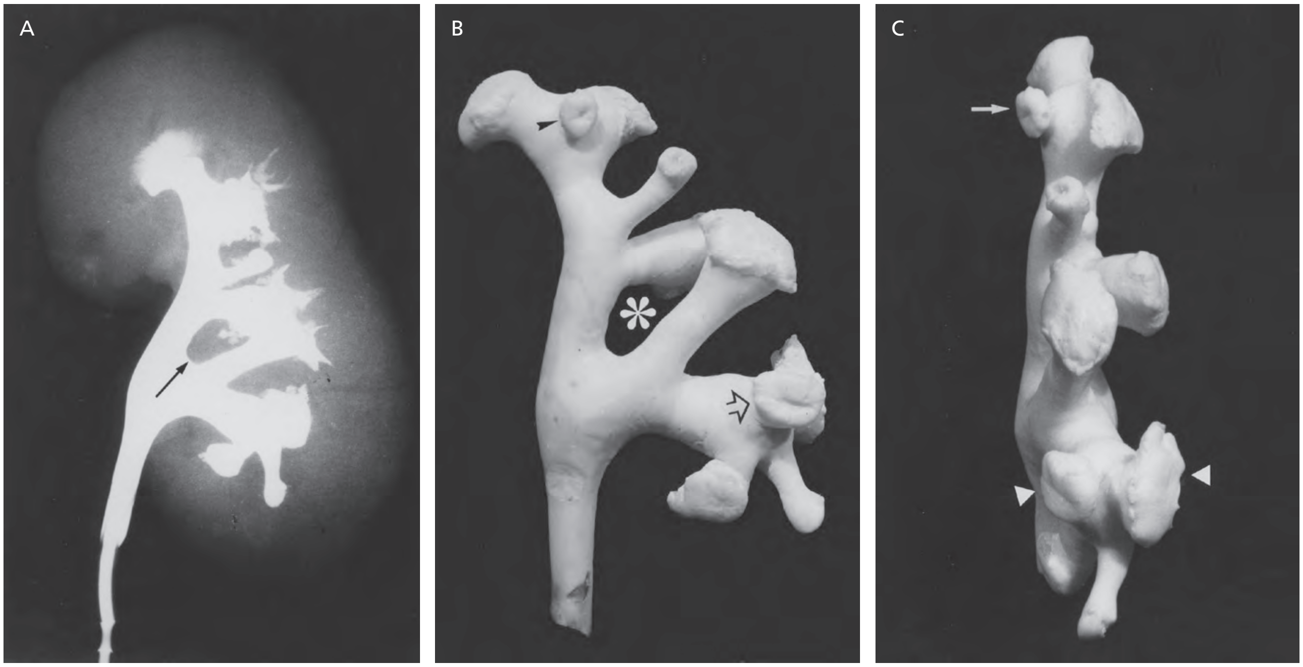

Figure 6.20 Comparative study between radiographic view of a left kidney and its corresponding three-dimensional (3D) endocast. (A) Anterior view of a retrograde pyelogram shows a radiographic image of the interpelviocalyceal region (arrow). (B) Anterior view of the corresponding 3D endocast. The asterisk denotes the interpelviocalyceal space; the arrowhead points to a minor calyx perpendicular to and superimposed on the surface of a superior major calyx, which cannot be seen on the pyelogram; and the open arrow points to an anterior minor calyx superimposed on the posterior minor calyx. It can be difficult to make the distinction between these features on a pyelogram. (C) Oblique view of the same endocast as in B. The arrow points to a perpendicular minor calyx in the superior calyceal group; and arrowheads to the distinction between the anterior and posterior minor calyces, which are superimposed on the pyelogram (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

Crossed calyces

In 17.2% of the endocasts, the kidney midzone (hilar) was drained simultaneously by crossed calyces, one draining into the superior calyceal group and the other into the inferior calyceal group. On the pyelograms, the crossed calyces (laterally) and the renal pelvis (medially) outlined a radiotransparent region that we termed the interpelviocalyceal region (Figure 6.20A). In the 3D endocasts, that same region appeared as a space (Figure 6.20B) [9, 11, 12].

The interpelviocalyceal space may have different shapes: lozenge-like (the most common), long and narrow, and even small and round, depending on the shape of the calyces and the shape of the renal pelvis (Figure 6.21). Regardless of the form assumed by the interpelviocalyceal space, it is the result of crossed calyces in the mid kidney.

When the crossed calyces were in the mid kidney, the calyx draining into the inferior calyceal group was in the ventral position in 87.5% of the endocasts [9, 11, 12] (Figure 6.22). In some cases, even when radiographically the calyx draining into the inferior group was apparently in the dorsal position, we verified its ventral position on the endocast (Figure 6.22). This constant spatial arrangement is noteworthy for endourologic maneuvers. If the intention is to access the renal pelvis via a crossed calyx or to access a crossed calyx via the renal pelvis, it is useful to remember that the calyx draining into the inferior calyceal group is almost always in the ventral position. It is also worthy of remark that detection of an interpelviocalyceal region on the pyelograms is an indirect sign of crossed calyces in the kidney midzone.

Position of the calyces relative to the lateral kidney margin

In 39 of the 140 endocasts (27.8%), the anterior calyces had a more lateral (peripheral) position than the posterior calyces (Figure 6.23). In 27 endocasts (19.3%), the posterior calyces were in a more lateral position than the anterior calyces (Figure 6.24). In the majority of the endocasts (74; 52.9%), the anterior and posterior calyces had varied positions: superimposed or alternately distributed (in one region the most lateral were the anterior calyces, and in another, the posterior calyces) (Figure 6.25).

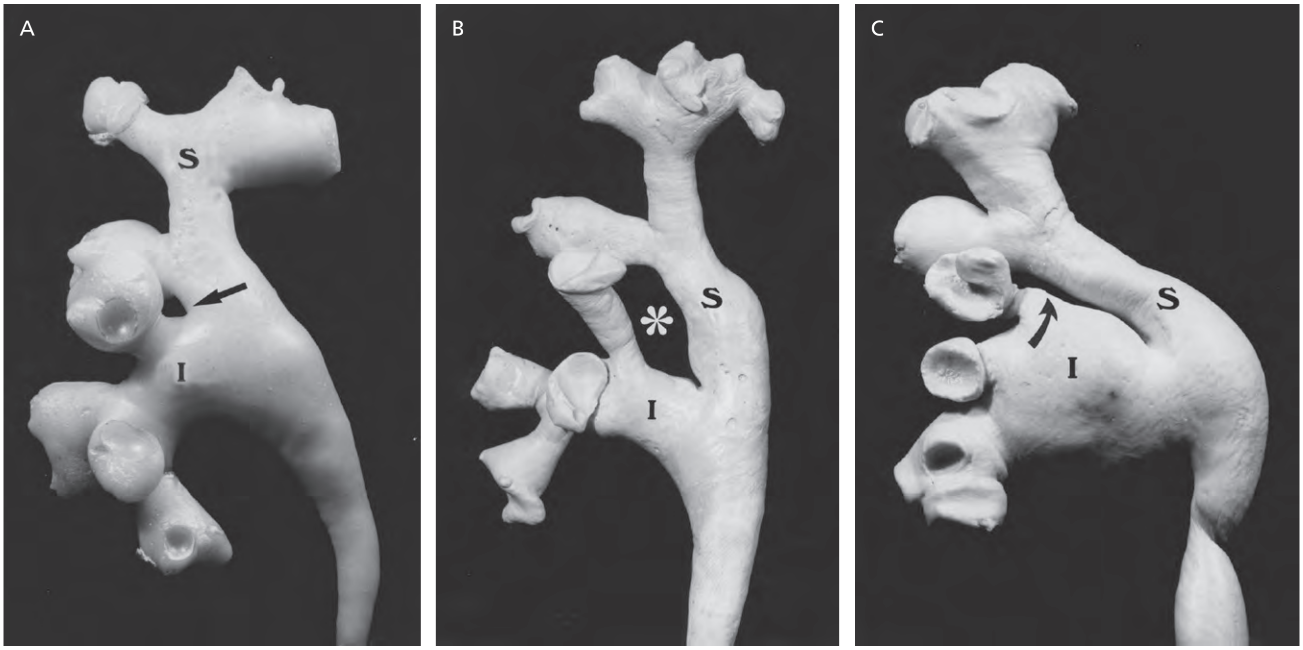

Figure 6.21 Anterior view of right pelviocalyceal endocasts. This shows the different shapes that the interpelviocalyceal (IPC) space may assume: (A) small and round IPC space (arrow); (B) lozenge-like IPC space (most common shape) (asterisk); (C) long and narrow IPC space (curved arrow). S, superior calyceal group; I, inferior calyceal group (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

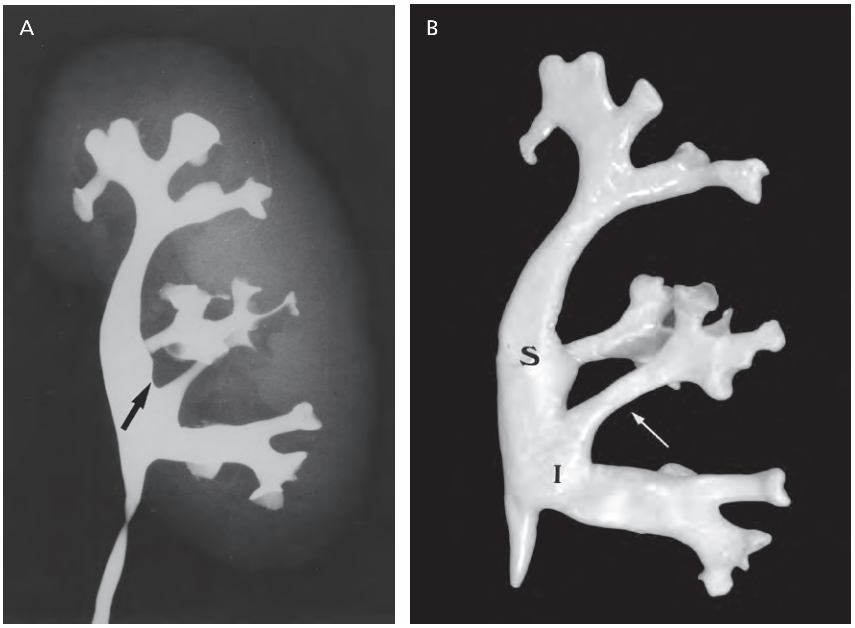

Figure 6.22 Comparative study between a retrograde pyelogram of a left kidney and its corresponding three-dimensional (3D) endocast of the pelviocalyceal system. (A) Anterior view of a retrograde pyelogram shows the radiographic image of the interpelviocalyceal (IPC) region (arrow). (B) Anterior view of the corresponding 3D endocast. The arrow points to the calyx which is draining into the inferior calyceal group in the ventral position (87.7% of the endocasts of the IPC space). S, superior calyceal group; I, inferior calyceal group (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

Since the first choice of access to the collecting system is through a posterior calyx, much effort has been made to determine preoperatively which calyces are anterior and which posterior. Previous studies have presented contradictory results and lead to misunderstanding of this subject [15]. We have described the type of kidney collecting system found in the majority of the endocasts, in which the calyces are disposed in various positions (superimposed or alternately distributed), and can affirm that the position of the calyces cannot be defined as more lateral or more medial. Considering the large variation of position of the calyces (>50% in different positions), we believe that precise determination of calyceal position is difficult with the common radiologic

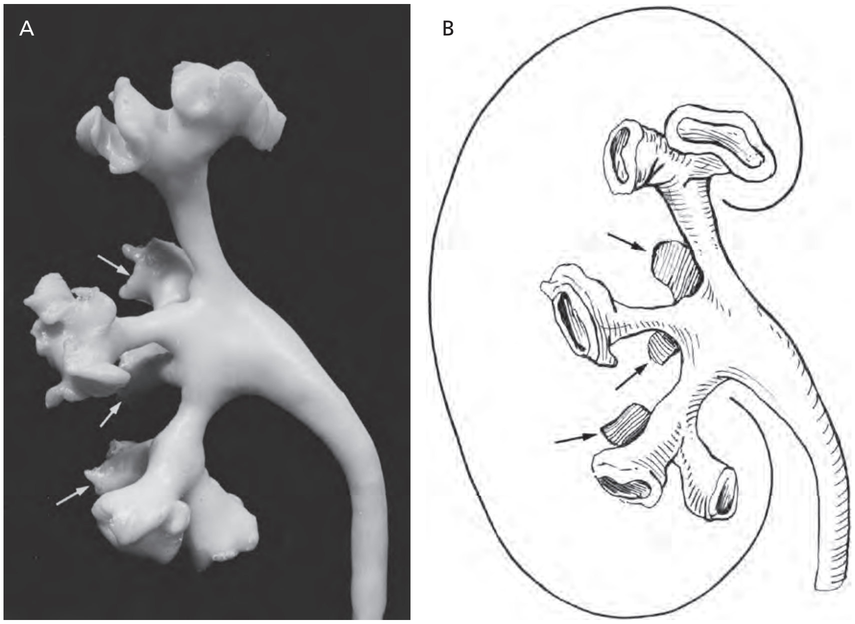

Figure 6.23 Position of the calyces relative to the lateral margin of the kidney. (A) Anterior view of a right pelviocalyceal endocast, which shows the anterior calyces have a more lateral (peripheral) position than the posterior calyces (arrows). This means that the posterior calyces are located medially. (B) Schematic of the endocast shown in A. This shows the peripheral calyces in the anterior plane and the medial calyces (arrows) in the posterior plane (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

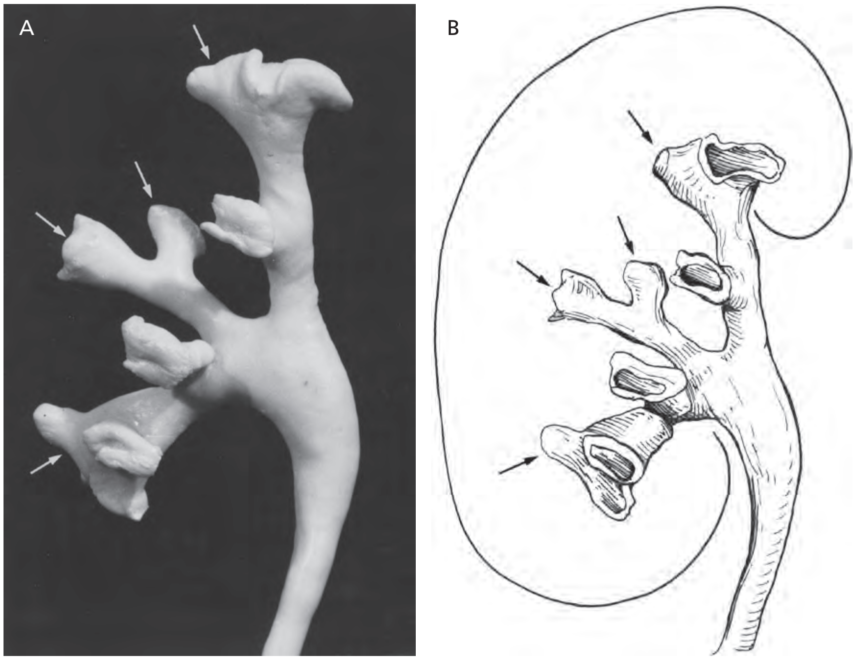

Figure 6.24 Position of the calyces relative to the lateral margin of the kidney. (A) Anterior view of a right pelviocalyceal endocast. This shows that the posterior calyces (arrows) have a more lateral (peripheral) position than the anterior calyces. (B) Schematic of the endocast shown in A. This shows the peripheral calyces in the posterior plane (arrows) and the medial calyces in the anterior plane (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

methods, even using oblique and lateral views [9, 11]. To solve this problem quickly and inexpensively, during endourologic procedures, with the patient in the prone position, room air should be injected into the collecting system and this will rise to the more posterior portions of the collecting system, determining which calyces are located posteriorly (radiolucent contrast) [11, 12, 16].

Position of the calyces relative to the polar regions and kidney midzone

The superior pole was drained by a midline calyceal infundibulum in 98.6% of the endocasts (Figure 6.26). The midzone (hilar) was drained by paired calyces that were arranged in two rows (anterior and posterior) in 95.7% of the endocasts (Figure 6.26). The inferior pole

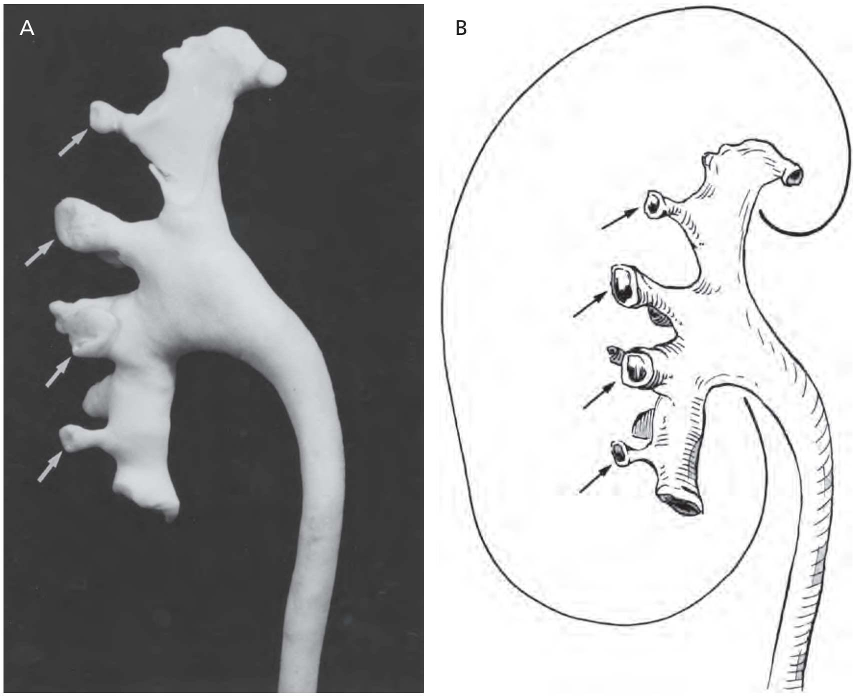

Figure 6.25 Position of the calyces relative to the lateral margin of the kidney. (A) Anterior view of a right pelviocalyceal endocast, and (B) schematic of this endocast. The calyces in the anterior plane (arrows) are located alternately relative to the lateral margin of the kidney, i.e. in one region they are more lateral and in another they are more medial. (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

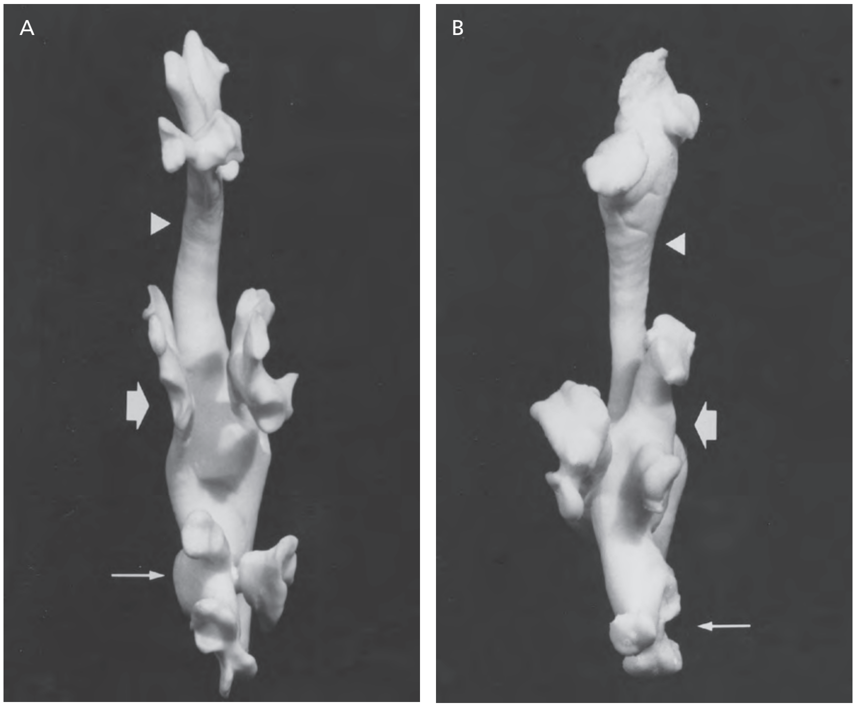

Figure 6.26 Position of calyces relative to the polar regions and kidney midzone. (A) Lateral view of a left pelviocalyceal endocast. The superior pole is drained by a single midline calyceal infundibulum (arrowhead). The midzone (hilar) is drained by paired calyces arranged in two rows (short arrow); anterior and posterior. The inferior pole is drained by paired calyces arranged in two rows (long arrow). (B) Lateral view of a right pelviocalyceal endocast. The superior pole is drained by a single midline calyceal infundibulum (arrowhead). The midzone is drained by paired calyces arranged in two rows (short arrow); anterior and posterior. The inferior pole is drained by only one midline calyceal infundibulum (long arrow) (Renal Anatomy Applied to Urology, Endourology, and Interventional Radiology, Sampaio FJB, Uflacker R, eds., Thieme, 1993 (reprinted with permission)).

was drained by paired calyces arranged in two rows in 81 endocasts (57.9%) (Figure 6.26A) and by a single midline calyceal infundibulum in 59 endocasts (42.1%) (Figure 6.26B).

With regard to the calyceal drainage of the kidney polar regions, many investigators have affirmed that there usually is only one calyceal infundibulum draining each pole [3, 10, 14]. In our study, the superior pole was drained by only one midline calyceal infundibulum in 98.6% of the endocasts. However, the inferior pole was drained by paired calyces arranged in two rows in 81 of the 140 endocasts (57.9%) and by one midline calyceal infundibulum in 59 endocasts (42.1%) (Figure 6.26). These results are important in endourology; it will be easier to access endoscopically a polar region drained by a single infundibulum, which usually has a suitable diameter, rather than a polar region drained by paired calyces (Figure 6.26). Because the inferior pole is drained by paired calyces in 57.9% of the endocasts, this anatomic detail must be kept in mind, both to plan and perform the intrarenal access and endoscopic procedures in the inferior pole. The calyceal drainage of superior and inferior poles is also of utmost importance in ESWL [13, 17]. Concerning the kidney midzone (hilar) drainage, our results show that this region is drained by paired calyces arranged in two rows (anterior and posterior) in 95.7% of the endocasts (Figure 6.26), which is of relevance to endourologists accessing and treating the mid kidney.

Anatomic relationship of intrarenal vessels (arteries and veins) with the kidney collecting system: importance for puncture intrarenal access

Percutaneous nephrostomy is the procedure of choice for temporary drainage of urine and for gaining access to the kidney during numerous endourologic and interventional procedures. The development of new percutaneous techniques, as well as a variety of instruments, has enabled the replacement of several open surgeries by percutaneous therapy (renal abscess, calyceal diverticulum, infundibular stenosis, ureteropelvic junction obstruction (UPJO), some cases of upper tract urothelial tumors, and even nephrectomy) [18–20]. Percutaneous procedures are relatively invasive and complications may occur. One of the most significant complications is vascular injury that occurs when the urologist is obtaining intrarenal access. This problem may have several consequences, including intraoperative hemorrhage, hypotension, loss of functioning renal parenchyma, arteriovenous fistula, and pseudoaneurysm [21–25].

The goal of this section is to offer a detailed anatomic depiction of the intrarenal vessels and their relationships to the collecting system, and show how to perform safe percutaneous intrarenal access by keeping as many renal vessels as possible intact during puncture.

We analyzed 62 retrograde pyelograms and their corresponding 3D polyester resin corrosion endocasts of the kidney collecting system, together with the intrarenal arteries and veins, obtained from fresh cadavers.

The kidneys were punctured under fluoroscopic guidance and the endocasts obtained with needles positioned at the site of puncture (Figure 6.27). For comparative analysis, we studied kidneys that had been punctured through a calyceal infundibulum and kidneys punctured through a calyceal fornix.

Intrarenal access through an infundibulum

Figure 6.13 shows the basic anatomy of the renal collecting system. Keeping those anatomic landmarks in mind, note that a puncture through an infundibulum (in any region of the kidney) presents clear hazards [26].

Superior pole

Puncture is most dangerous through the upper pole infundibulum because this region is surrounded almost completely by large vessels (Figure 6.28). Infundibular

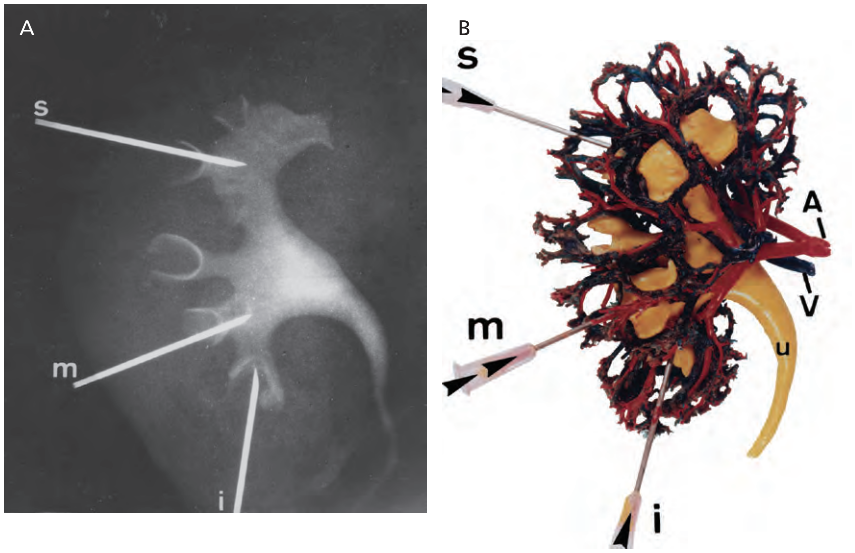

Figure 6.27 (A) Anterior view of a retrograde pyelogram from a right kidney showing the superior pole (s), mid kidney (m), and inferior pole (i) punctures. These punctures were performed after polyester resin injections into the arterial and venous systems, while the resins were still in the gel state. Note that the injected resins are not opaque to X-rays. (B) Posterior view of the corresponding corrosion endocast obtained after contrast removal and pelviocalyceal system injection with resin. The needles are maintained in their original places. s, superior pole puncture; m, mid kidney puncture; i, inferior pole puncture. The arrowheads show the tracts of the needles. A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

arteries and veins course parallel to the anterior and posterior aspects of the upper pole infundibulum. In our series, injury to an interlobar (infundibular) vessel was a common consequence of puncturing the upper pole infundibulum (67% of kidneys) (Figure 6.29); the injured vessel was an artery in 26% of those cases.

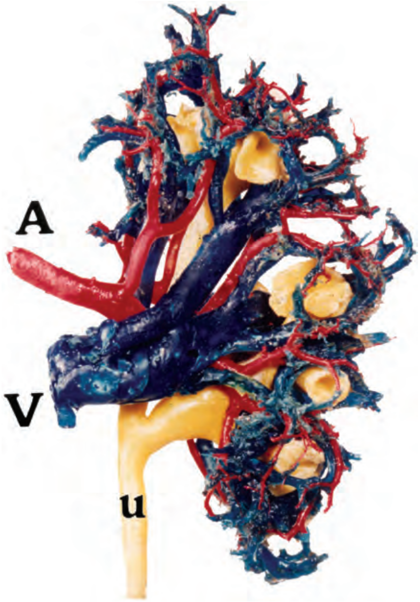

Figure 6.28 Oblique medial view of an endocast of arterial (A), venous (V), and pelviocalyceal systems from a left kidney. This shows the upper infundibulum almost completely encircled by infundibular arteries and veins. This anatomic arrangement makes upper pole infundibular puncture especially dangerous. A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

The most serious vascular accident in upper infundibulum puncture is lesion of the posterior segmental artery (retropelvic artery). This event may occur because this artery was crossed by and is related to the posterior surface of the upper infundibulum in 57% of the endocasts (Figure 6.30) [27]. Figure 6.31 shows an upper infundibulum puncture in which the needle tract produced complete laceration of the posterior segmental artery. Because the posterior segmental artery (retropelvic artery) may supply up to 50% of the renal parenchyma, injury to it may result in significant loss of functioning renal tissue, as well as causing hemorrhage [28].

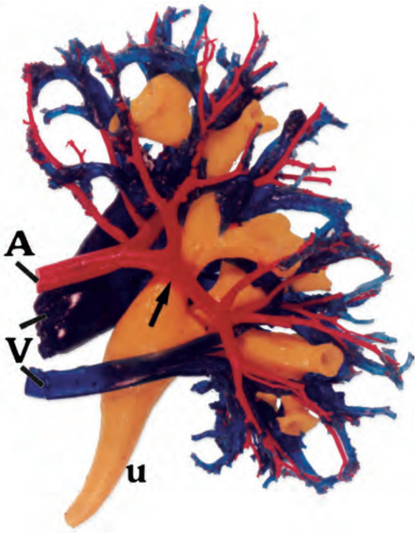

Figure 6.30 Posterior view of an endocast from a right kidney. This shows the posterior segmental artery (retropelvic artery) crossing the posterior surface of the upper infundibulum (arrow). A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

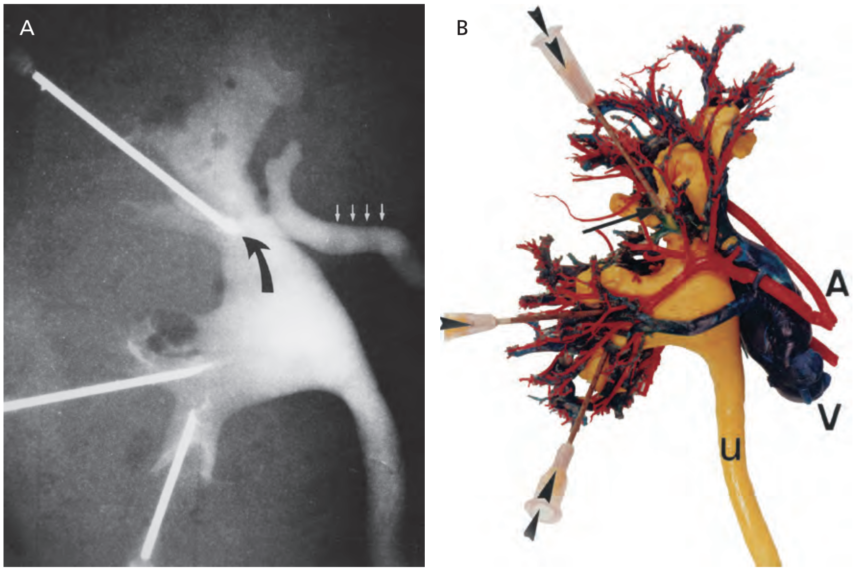

Figure 6.29 (A) Posterior view of a retrograde pyelogram from a left kidney. Puncture performed through the upper infundibulum has injured an infundibular vein (curved arrow). Note the contrast in the retropelvic vein (short arrows). (B) Posterior view of the corresponding endocast reveals the site of the lesion (arrow). Arrowheads show the needle tracts. A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

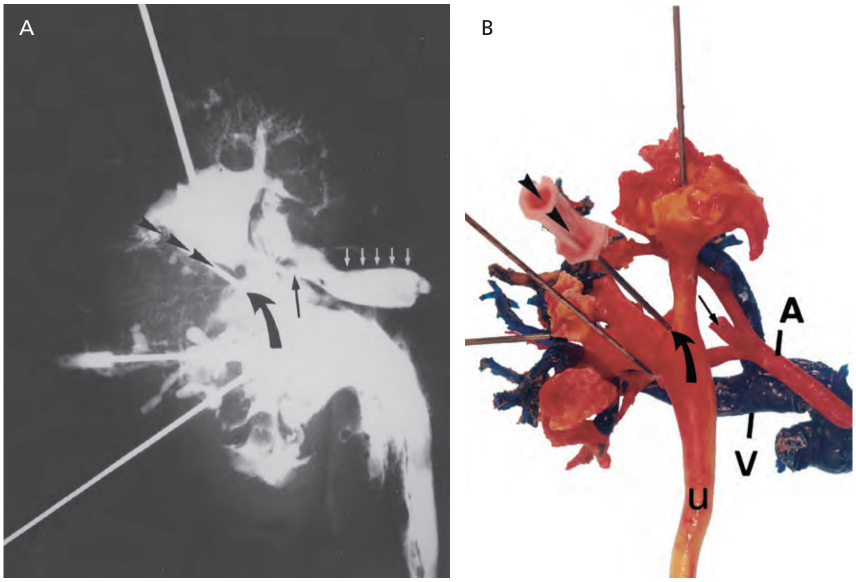

Figure 6.31 (A) Posterior view of a retrograde pyelogram from a left kidney. This shows contrast extravasation, and contrast in the arterial system and main trunk of the renal artery (short arrows). The retropelvic artery was injured by the needle (needle tracts shown by the arrowheads). The curved arrow points to the site of the lesion; the long arrow points to the retropelvic artery filled with contrast extravasated from the collecting system. (B) Posterior view of the corresponding endocast. This shows the divided retropelvic artery (arrow) and the needle (arrowheads) responsible for the lesion (curved arrow). A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

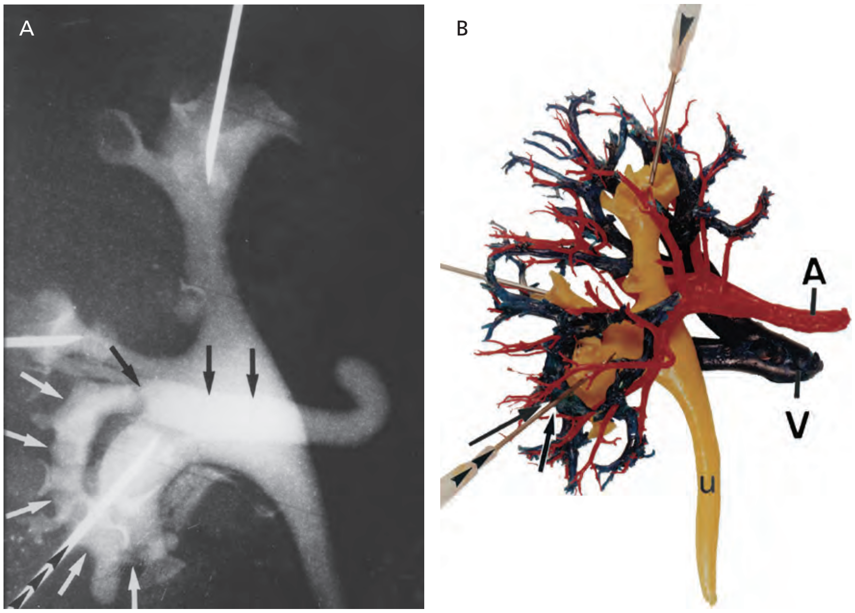

Figure 6.32 (A) Posterior view of a retrograde pyelogram from a left kidney. This shows a puncture performed through the inferior infundibulum. A venous lesion and the contrast in a large venous arcade draining to the retropelvic vein (arrows) can be seen. The arrowheads show the tract of the needle.
(B) Posterior view of the corresponding endocast reveals the site of the lesion in the venous arcade (arrows). The arrowheads show the tracts of the needles. A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio *et al*. [24], with permission).

Middle kidney

Intrarenal access through the mid kidney infundibulum caused arterial lesion in 23% of the kidneys studied. The middle branch of the posterior segmental artery was injured more often than any other vessel.

Inferior pole

The posterior aspect of the lower pole infundibulum is widely presumed by endourologists and interventional radiologists to be free of arteries. It is considered, therefore, to be a safe region through which to gain access to the collecting system and to place a nephrostomy tube. In about 38% of the kidneys examined, however, an infundibular artery was found in this region [27]. Thus, significant complications may develop as a consequence of a posterior approach through the supposedly vessel-free lower infundibulum [22, 25, 26]. We found an arterial injury in 13% of kidneys we had punctured through the lower pole infundibulum.

Concerning the veins, we found large venous anastomoses, similar to collars, around the calyceal infundibula (the so-called calyceal necks) in many of the kidneys we studied [7]. Puncture through the lower pole infundibulum therefore also risks injury to a venous arcade (Figure 6.32). A venous lesion usually heals spontaneously, but consequent hemorrhage may be problematic during the procedure.

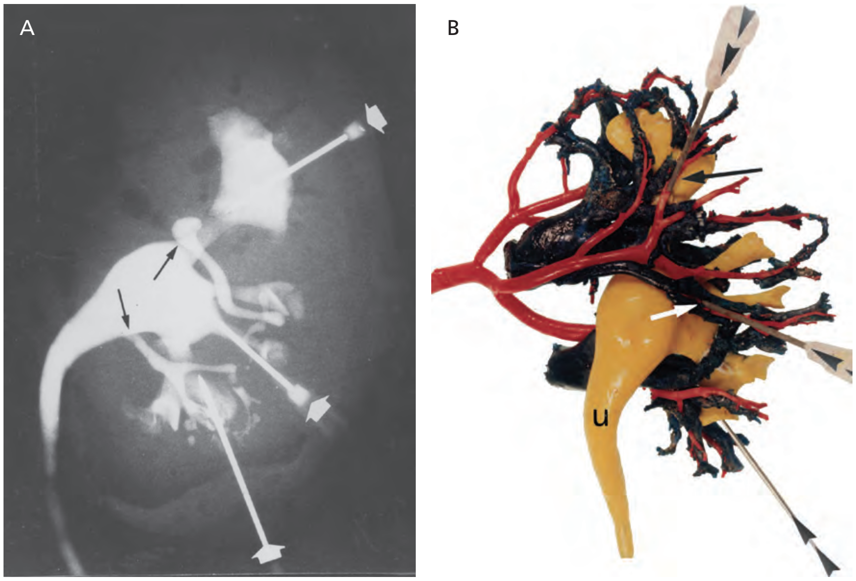

Figure 6.33 (A) Posterior view of a retrograde pyelogram from a right kidney reveals superior, middle, and inferior punctures (arrowheads) and contrast in the superior and inferior infundibular arteries (arrows).
(B) Posterior view of the corresponding endocast reveals injury to an upper infundibular artery (black arrow). The mid kidney puncture (white arrow) was a through-and-through (two walls) puncture and injured an anterior segmental artery. The injured vessel furnished the posteroinferior branch filled with contrast on the pyelogram. The arrowheads show the tracts of the needles. U, ureter (reproduced from Sampaio *et al*. [24], with permission).

Our findings clearly demonstrate that percutaneous nephrostomy through an infundibulum of a calyx is not a safe route, because this type of access poses an important risk of significant bleeding from interlobar (infundibular) vessels.

Infundibular puncture also creates the hazard of through-and-through (two-wall) puncture of the collecting system (Figure 6.33). Because major segmental branches of the renal artery, as well as major tributaries of the renal vein, are positioned on the anterior surface of the renal pelvis, marked hemorrhage may occur as a result of an anterior through-and-through perforation. In addition, effective tamponade of injured anterior vessels is difficult because they lie distantly in the nephrostomy tract [24, 26, 29].

Although infundibular access is feasible in some circumstances and must be considered in specific situations (e.g. some difficult anatomic cases), the surgeon must evaluate the risk of an arterial lesion, primarily in the superior pole and in the mid kidney [24].

Intrarenal access through the renal pelvis

Direct puncture of the renal pelvis for endourologic surgery should never be performed. Besides the fact that the nephrostomy tube inserted at this site is easily dislodged and difficult to reintroduce during the operative maneuvers, renal pelvis puncture has a prohibitive and unnecessary risk of injuring a retropelvic vessel (artery and/or vein) [7, 22, 27].

Intrarenal access through a calyceal fornix

When we made a puncture through a fornix of a calyx, venous injury occurred in fewer than 8% of the kidneys. These injuries occurred indiscriminately in the upper pole, mid pole, and lower pole calyces. We did not detect any arterial lesions as a consequence of a forniceal puncture [24].

Where to puncture for intrarenal access

In conclusion, the high rate of vascular injury and the possibility of associated complications mean that *a nephrostomy tube should not be placed through an infundibulum of a calyx* (Figure 6.34). On the other hand, and regardless of the region of the kidney, *puncture and placement of a nephrostomy tube through a fornix of a calyx is safe* and should be the site chosen by the operator (Figure 6.35). Even in the superior pole, intrarenal puncture through a calyceal fornix is harmless (Figure 6.36). In addition, when puncturing through a fornix of a calyx, in case of lesion, injury is always to a peripheric vessel, such as a small venous arcade (Figure 6.37).

Vascular anatomy and intrarenal endourologic surgery

The development of new endourologic procedures and techniques, as well as special operative instruments, allowed an important improvement in endourologic intrarenal surgery to treat numerous renal diseases and/or help with the management of difficult cases in endourology [19, 20, 29, 30].

A serious and troublesome complication of endoscopic intrarenal operation is bleeding from an injured vessel [29, 30]. To avoid such injury, the position of the intrarenal vascular structures must be known in relation to the collecting system. That knowledge must consider

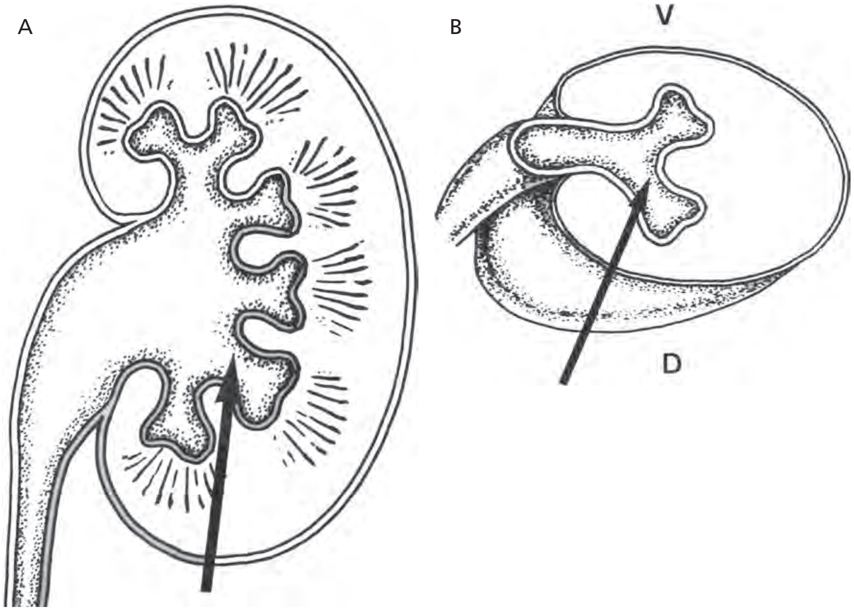

Figure 6.34 (A) Schematic of a posterior view of a longitudinal section of a right kidney showing an intrarenal puncture performed through a calyceal infundibulum (arrow). This type of puncture should *not* be performed because it carries a high risk of vascular injury. (B) Schematic of a superior view of a transverse section of a kidney also shows an intrarenal puncture through a calyceal infundibulum (arrow); again this is *not* a recommended route. V, ventral region; D, dorsal region.

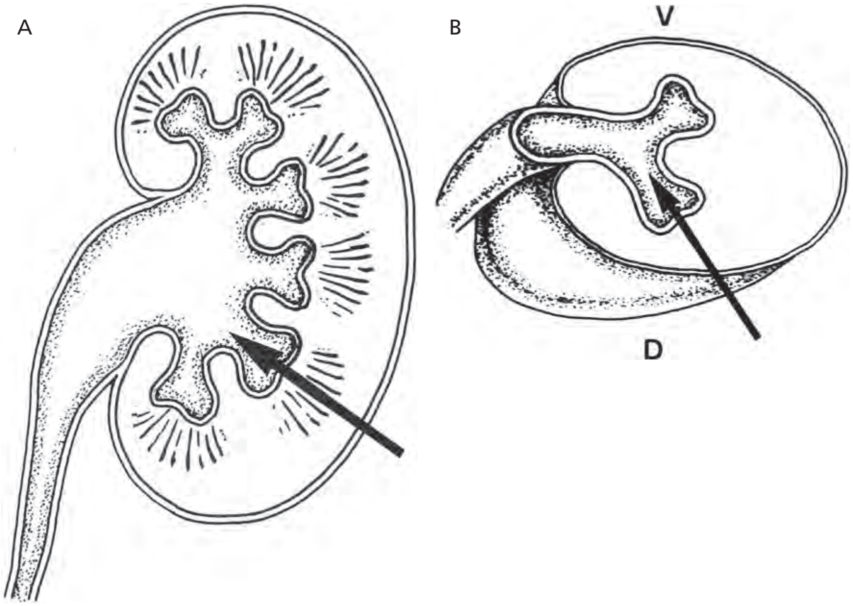

Figure 6.35 (A) Schematic of a posterior view of a longitudinal section of a right kidney showing an intrarenal puncture performed through a calyceal fornix (arrow). This type of puncture is safe and is associated with a very low incidence of vascular injury. (B) Schematic of a superior view of a transverse section of the kidney shows an intrarenal puncture through a calyceal fornix (arrow), a route that is strongly recommended. V, ventral region; D, dorsal region.

each specific kidney region with emphasis on the infundibular regions [6, 31].

We analyzed 82, 3D polyester resin corrosion endocasts of the kidney collecting system together with the intrarenal arteries, and 52 endocasts of the kidney collecting system together with the intrarenal veins, obtained according to the injection–corrosion technique described previously [7, 11, 27].

Regional vascular anatomy of the kidney

Superior pole

The upper infundibulum was almost completely surrounded by segmental or interlobar (infundibular) arteries in 86.6% of the endocasts (Figure 6.38). In 84.6% of the endocasts, an anterior and a posterior venous plexus were in close relationship to the upper infundibulum (Figure 6.39).

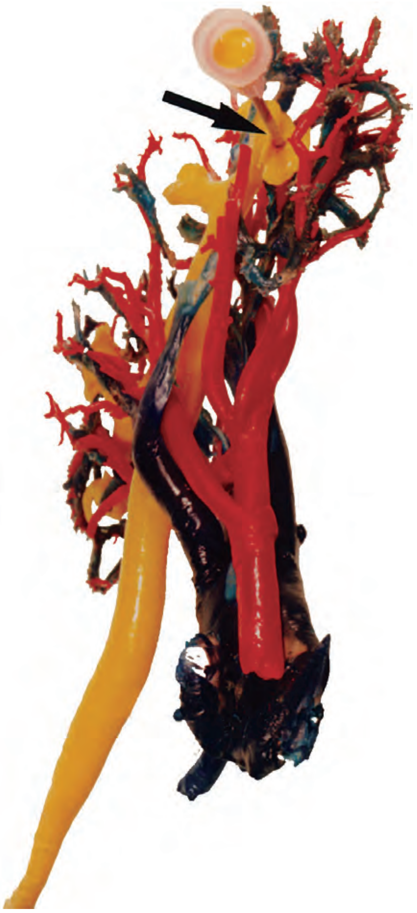

Figure 6.36 Superior view of an endocast from a left kidney shows that, even in the superior pole, a puncture through the fornix of a calyx (arrow) is safe.

Middle kidney

The anterior aspect of the mid kidney infundibulum of a major or a minor calyx was in close relationship to a segmental or an infundibular artery in 65% of the endocasts (Figure 6.38A). In the posterior aspect of all the endocasts, we found at least one mid kidney infundibulum in close relationship to the mid subdivision branch of the posterior segmental artery (retropelvic artery) (Figure 6.38B).

Concerning the veins, the anterior aspect of a middle infundibulum was in contact with an anterior tributary of the renal vein in 71% of the endocasts. The posterior aspect of a middle infundibulum was in close relationship to a posterior tributary of the renal vein in 21% of the endocasts (Figure 6.39).

The vascular relations to mid kidney infundibula are very variable because they follow the variations in the calyces, of which there are many in this region [8, 27].

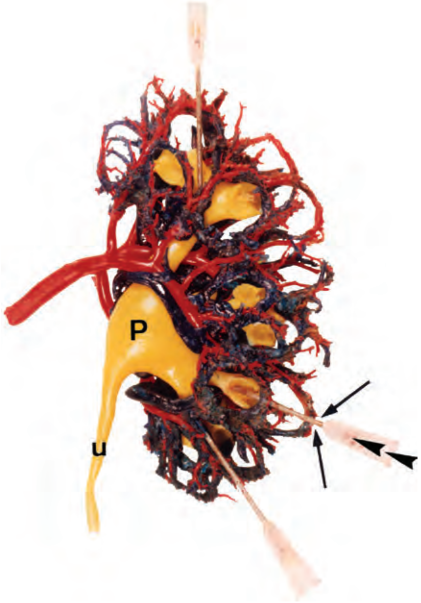

Figure 6.37 Posterior view of an endocast from a right kidney with an inferior puncture performed through a fornix of a calyx. The arrows point to a lesion in a small peripheric venous arcade. The arrowheads show the needle tract. P, renal pelvis; u, ureter.

Inferior pole

In all endocasts, the lower infundibular anterior aspect of a major or a minor calyx was in close relationship to a branch of the anteroinferior or inferior segmental artery (Figure 6.38A). Concerning the posterior aspect, in 38% of the endocasts, an extension of the posterior segmental artery itself was in close relationship to the lower major calyceal infundibulum. In the other 62%, the posterior aspect of the lower major calyceal infundibulum was free from arteries; nevertheless, the posterior aspect of the lowermost minor calyx infundibulum was related to an artery in all endocasts (Figure 6.38B).

With respect to veins, the anterior aspect of at least one lower infundibulum was in contact with an intrarenal vein in all endocasts. The posterior aspect of a lower infundibulum was in close relationship to a large tributary of the renal vein in 21% of the endocasts (Figure 6.39). In addition, in the inferior pole, a collar-like venous anastomosis around the minor calyces infundibula (calyceal necks) is often found (Figure 6.39).

Where to incise the kidney collecting system based on vascular anatomy

If any intrarenal operation is necessary to free entrapped stones, to treat strictures and diverticula, to incise a narrowed infundibulum, to correct other anomalies that can cause stone formation, and even to facilitate the

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Figure 6.38 (A) Anterior view of an endocast (pelviocalyceal system and arteries) from a right kidney showing the anterior surface of the upper infundibulum in close relationship to the segmental and interlobar (infundibular) arteries (arrowheads). The arrow points to an artery coursing in the anterior surface of the mid kidney infundibulum. The open arrow points to the extension of the anteroinferior segmental artery close to the lower infundibulum anterior surface of a minor calyx. (B) Posterior view of the endocast shown in A shows the infundibular arteries in close relationship to the posterior surface of the upper infundibulum (arrowheads). The arrow points to the mid subdivision branch of the posterior segmental artery (retropelvic artery) crossing the posterior aspect of a mid kidney infundibulum. The open arrow indicates an infundibular artery close to the posterior aspect of the infundibulum of the lowermost calyx (reproduced from Sampaio [31], with permission).

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Figure 6.39 Posterior view of an endocast (pelviocalyceal system and veins) from a right kidney shows a large venous plexus in close relationship to the upper infundibulum (short arrow). The arrowhead points to the posterior aspect of the lower infundibulum in close relationship to a large vein. The arrows encircle the collar-like venous anastomosis around the neck of the lower minor calyx (reproduced from Sampaio [31], with permission).

access for the rigid nephroscope to a specific calyx [29, 30], the operator must visualize the arterial relationships found most frequently in the area to be incised. It was established that the area first must be examined under direct vision to be certain that there are no arterial pulsations [29], and then a short incision to a depth of 1–2 mm may be made. If necessary, e.g. the infundibulum remains thick, it is better to make a second incision in a different site than to deepen the first incision, due to the risk of injuring a large vessel [29, 31].

Even taking into account these technical recommendations, significant bleeding may occur during intrarenal endourologic surgery [29, 30]. Also, arterial pulsations are not always readily identifiable endoscopically during surgery, mainly because patients may be hypotensive due to anesthesia [6, 31].

Although it is difficult to eliminate bleeding completely, maintenance of anatomic orientation during all steps of the procedure and a thorough knowledge concerning the relationship between the pelviocalyceal system and the vessels are imperative to reduce vascular complications, improving the performance and safety of operations.

On the basis of the anatomic vascular background presented here, and considering that the circumference of an infundibulum is composed of four quadrants, we

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Figure 6.40 Schematics of the renal collecting system. (A) Anterior view of a right kidney pelviocalyceal system shows the sites to be incised in infundibular stenosis; s, superior quadrant; i inferior quadrant. (B) Transverse section through an infundibulum shows the four quadrants that comprise the infundibular circumference and the two preferred areas to be incised (s, superior quadrant; i, inferior quadrant). This also shows the anterior (a) and posterior (p) quadrants, which are usually closely related to vessels (reproduced from Sampaio [31], with permission).

advise that the infundibular incision is made in the superior or inferior quadrant (Figure 6.40), because in general this area is not in relation to large vascular structures. In contrast, the posterior and, especially, the anterior aspects of infundibular surfaces are frequently related to intralobar (infundibular) vessels (Figure 6.40). *Anterior incisions must always be avoided.* From an anatomic standpoint, if more than one infundibular incision is necessary, we recommend the following sequence:

- First incision in the superior quadrant;
- Second incision in the inferior quadrant;
- Third incision between the superior and posterior quadrant;
- Fourth incision between the inferior and the posterior quadrant;
- Fifth incision in the posterior quadrant.

Because the free circulation throughout the venous system prevents parenchyma loss and ischemia, arteries are considered of utmost importance in intrarenal endosurgery. Nevertheless, veins should be considered as well, because an injury to a large vein would result in important and troublesome back bleeding. Moreover, as the veins do not pulsate, they cannot be perceived through the nephroscope; therefore, only knowledge of the anatomic relationships between the veins and the collecting system will avoid venous lesion. If it is necessary to make an incision in the infundibulum (neck) of a minor calyx, especially in the lower calyces, the operator should remember that the regions close to the calyceal cups may be surrounded by venous collars (Figure 6.39). In these cases, it is better to perform short radial incisions (up to 1 mm in depth) in the quadrants described previously, in order to avoid venous collar lesions.

Vascular anatomy of the ureteropelvic junction: importance for endopyelotomy

Since its clinical introduction, the endoscopic treatment of UPJO, endopyelotomy, has almost completely replaced open pyeloplasty for this procedure [32–37]. It has a comparable success rate to open surgery and is applicable to congenital and acquired conditions [35–38]. Today, endopyelotomy is a common procedure for both primary and secondary UPJO [39]. In spite of the recently high success rate of laparoscopic pyeloplasty, endopyelotomy continues to be more commonly performed in academic centers [40].

Because endopyelotomy is based on an intubated pyeloplasty (ureteropelvic incision followed by stenting for 1–6 weeks) [32, 35–38, 41], to be successful the endoscopist must incise the full thickness of the muscle at the stenotic wall of the UPJ until periureteral fat becomes visible. This deep incision must be carried out whether the approach is through a nephrostomy tract, by ureteroscopy, or with an Acucise catheter, and whether the instrument used to incise the stricture is a cold knife or an electrosurgical probe [42].

Incising the UPJ until the perirenal space is entered obviously carries the risk of injuring a retroperitoneal vessel [43–45]. In fact, the most significant complication

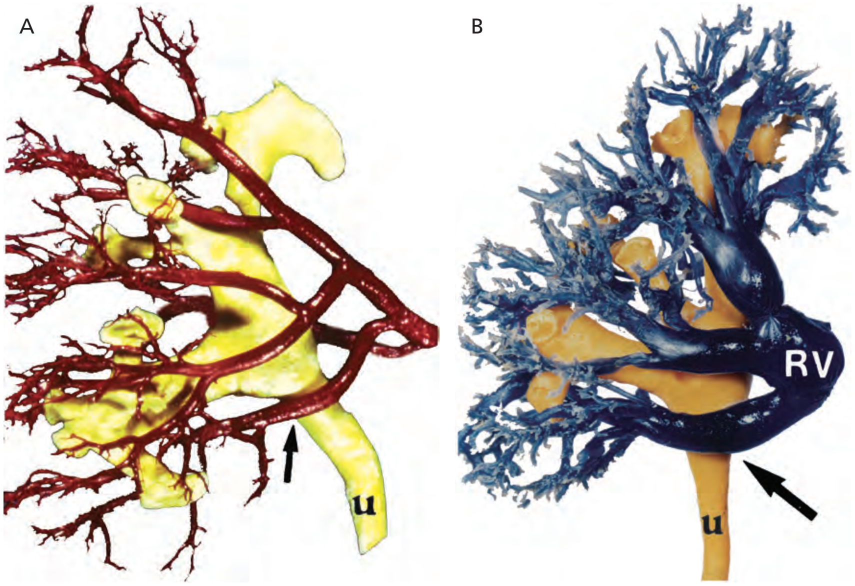

Figure 6.41 (A) Anterior view of a right kidney endocast (pelviocalyceal system together with the intrarenal arteries) shows a close relationship between the inferior segmental artery and the anterior surface of the ureteropelvic junction (UPJ; arrow). u, ureter. (B) Anterior view of a right kidney endocast (pelviocalyceal system together with the intrarenal veins) shows a close relationship between a vein draining the lower pole and the UPJ (arrow). RV, renal vein; u, ureter (reproduced from Sampaio and Favorito [44], with permission).

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Figure 6.42 Anterior view of a right kidney endocast (pelviocalyceal system together with the intrarenal arteries and veins) shows the anterior surface of the ureteropelvic junction in close relationship with the inferior segmental artery (arrowhead) and a tributary of the renal vein (arrow). A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio [59], with permission).

of this procedure is vascular injury, followed by severe hemorrhage and/or formation of an arteriovenous fistula [33, 34, 36, 46–50]. To protect the arteries from lesion, it has been recommended to examine via intrarenal endoscopy the area to be incised for any arterial pulsation and, if detected, to avoid incising that site. Nevertheless, arterial pulsations are not always readily identifiable endoscopically during surgery, mainly because patients may be hypotensive due to anesthesia [31]. In addition, because veins do not pulsate, endoscopic examination of the area to be incised will not prevent a venous lesion [7, 31].

The risk of injuring a large vessel during endopyelotomy can be greatly reduced or even eliminated if the endourologist understands and keeps in mind the 3D vascular relationships to the UPJ [44, 45, 51]. This section describes the vascular anatomy of the UPJ and this should be used to perform endopyelotomy safely and efficiently.

We analyzed 146 3D polyester resin corrosion endocasts of the pelviocalyceal system together with the intrarenal arteries and veins [45].

Anterior vascular ureteropelvic junction relationships

In 65% of the endocasts there was a prominent artery, vein, or both vessels in close relationship with the ventral surface of the UPJ (Figures 6.41 and 6.42). Among these endocasts, the relationship was with the inferior segmental artery in 45% (Figure 6.43).

Concerning patient selection for treatment of UPJO, it remains controversial whether or not it is important to diagnose anterior crossing vessels. Van Cangh *et al.* obtained preoperative digital angiography in patients prior to endopyelotomy and found an associated vessel in 39% of those with UPJO [52]. These authors stated that the presence of an anterior crossing vessel with either mild or severe hydronephrosis resulted in a success rate of only 50% and 39%, respectively. More recently, Van Cangh *et al.* stated that significant risk factors for endopyelotomy failure are crossing vessels, degree of hydronephrosis, length of stricture, and renal function [53]. Rehman *et al.* emphasized the importance of spiral CT angiography for delineating the renal vascular anatomy before open retroperitoneal UPJO repair

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Figure 6.43 Anterior views of right (A) and left (B) kidney endocasts (pelviocalyceal system together with the intrarenal arteries) show a close relationship between the inferior segmental artery and the anterior surface of the ureteropelvic junction (arrows). u, ureter (reproduced from Sampaio [59], with permission).

[54]. They described two patients with repair failure of UPJO in whom anterior vessels were missed during open retroperitoneal surgery. Laparoscopic transperitoneal secondary dismembered pyeloplasty with posterior displacement of the crossing vessel was successfully performed in each case.

On the other hand, Smith stated that this kind of study would be justified only if there were evidence that such vessels were etiologic in UPJ obstruction or if there were a risk of incising the vessel during endopyelotomy [37]. More recently, Gupta and Smith stated that the current data suggest that the finding of crossing vessels preoperatively need not significantly influence the treatment given [55]. Corroborating this view, Nakada *et al*. reported that helical CT detected significant anterior or posterior crossing vessels in 38% of patients following successful endopyelotomy [56]. In their opinion, the adverse influence of the crossing vessel is not sufficient to justify the added expense of preoperative angiography, spiral CT, or endoluminal ultrasound. Also, documenting the presence of a crossing vessel is inadequate to confirm that the vessel is causing obstruction. None of the current UPJ imaging techniques can distinguish crossing arteries that are the direct cause of obstruction from those that are not [57, 58]. Therefore, in the absence of a prospective randomized trial comparing the results of open pyeloplasty and endopyelotomy, including the investigation of crossing vessels, the imaging of these crossing vessels before surgery is controversial.

It is worth pointing out that in Van Cangh *et al.*'s series, 39% of the patients had a crossing vessel anteriorly to the UPJ, and these were considered to be anomalous arteries [52]. This consideration disagrees with our extensive vascular anatomic studies [43–45, 59]. Of 280 endocasts of the pelviocalyceal system together with the intrarenal arteries and veins, we found a close relationship between a normal artery, vein, or both and the anterior surface of the UPJ in 65.1% (Figures 6.41–6.43) [45, 59]. In 45.2% of the endocasts there was a close relationship between the inferior segmental artery and the anterior surface of the UPJ when this vessel passed in front of this region to enter the inferior pole (Figure 6.43) [45, 59]. This vessel is neither accessory nor aberrant, but, rather, a normal segmental artery that maintains a consistent anatomic relationship with the anterior surface of the UPJ without compressing the junction [45, 59, 60]. The mere presence of crossing vessels in the UPJ does not mean that they are necessarily obstructive [37]. We consider that an anomalous artery crossing the UPJ and causing obstruction in 39% of patients, as described by Van Cangh *et al*. [52], is quite a high incidence. It is possible that many of the vessels seen close to the UPJ during angiography and described as anomalous were in fact normal segmental arteries. They may not cause the obstruction but rather increase the dilation of a redundant renal pelvis previously obstructed by a primary muscular defect at the UPJ. In such a situation, the dilated renal pelvis balloons over the anterior crossing vessel, and the resulting angulation appears to worsen the obstruction [45]. Therefore, the exact role of crossing vessels in obstruction and the success of endopyelotomy are yet to be determined [37, 55].

With respect to the presence of multiple renal arteries, we found an inferior polar artery crossing anteriorly to the UPJ in only 6.8% of 266 renal arterial pedicles analyzed (Figure 6.44) [61] Also, in only a few cases did this inferior polar artery pass close to the UPJ. Therefore, the

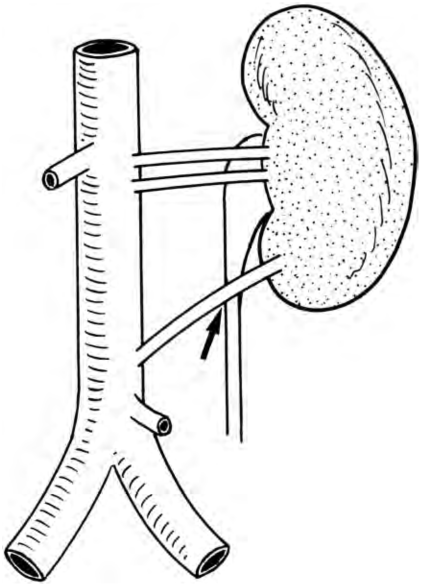

Figure 6.44 Schematic of an anterior view of a left kidney showing an inferior polar artery (arrow) crossing anterior to the ureteropelvic junction (incidence of 6.8%).

presence of an anomalous vessel crossing the UPJ and causing obstruction is uncommon.

For patients with a crossing vessel and minimal-to-moderate hydronephrosis, laparoscopic clipping and incision of the crossing artery has been reported [52]. We emphasize that this approach should not be used, because it results in loss of functioning renal parenchyma. It was well demonstrated and stressed that all renal arteries, even in cases of multiple arteries, are terminal vessels; therefore, clipping the vessel will cause renal infarction [28]. As we have shown previously, the artery supplying the inferior pole of the kidney (inferior segment) represents 7.4–38% of the total kidney area of functioning renal parenchyma (median area of the inferior segment, 22.6%) [28]. For that reason, if it is confirmed that the UPJO is caused by a crossing artery, open surgery or a laparoscopic pyeloplasty with transposition of the crossing vessel should be proposed rather than clipping it [59].

Posterior vascular ureteropelvic junction relationships

In 6.2% of the endocasts, we found a direct relationship between a large vessel (artery, vein, or both) and the dorsal surface of the UPJ (Figure 6.45). In all cases in which an artery crossed the dorsal surface of the UPJ (3.5%), the vessel was the posterior segmental artery, also known as the retropelvic artery (Figures 6.45 and 6.46).

Most authors recommend that the UPJ be incised alongside its posterolateral aspect, but our findings indicate that this poses a serious risk of injuring a retropelvic vessel. In fact, even when the procedure is performed by experienced endourologists, the incidence of severe hemorrhage when the UPJ is incised posterolaterally is 12% [36]. A posterior or posterolateral incision at the

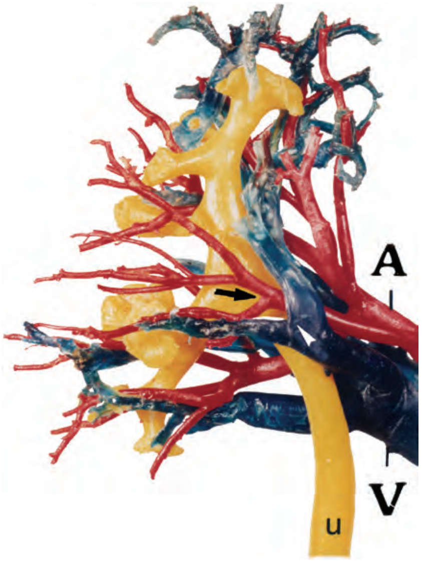

Figure 6.45 Posterior view of an endocast of a left kidney (pelviocalyceal system together with the intrarenal arteries and veins). A dorsal tributary of the renal vein (arrowhead) and the posterior segmental artery (retropelvic artery, arrow) are in close relationship to the posterior aspect of the ureteropelvic junction. A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio and Favorito [44], with permission).

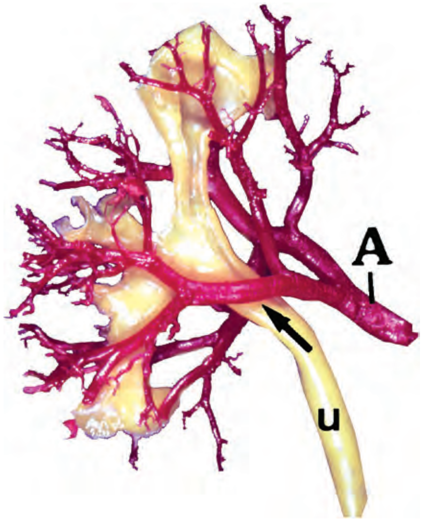

Figure 6.46 Posterior view of a left kidney endocast (pelviocalyceal system together with the intrarenal arteries and veins) shows the posterior segmental artery (retropelvic artery) in close relationship to the posterior aspect of the ureteropelvic junction (arrow). A, renal artery; u, ureter (reproduced from Sampaio and Favorito [44], with permission).

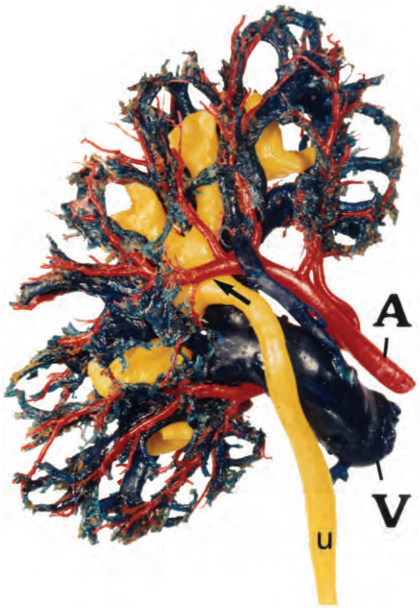

Figure 6.47 Posterior view of a left kidney endocast (pelviocalyceal system together with the intrarenal arteries and veins) shows the posterior segmental artery (retropelvic artery) crossing less than 1.5 cm (0.5 cm) above the posterior aspect of the ureteropelvic junction (arrow). A, renal artery; V, renal vein; u, ureter (reproduced from Sampaio and Favorito [44], with permission).

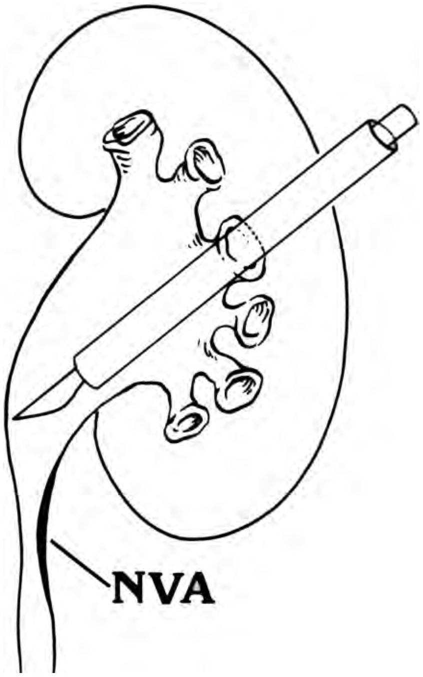

Figure 6.48 Schematic of an anterior view of a left kidney shows the area to be incised in endopyelotomy (arrow), the nonvascular area (NVA) of the ureteropelvic junction.

UPJ stenosis also presents the possibility of injury to the posterior segmental artery (retropelvic artery), which in addition to causing severe hemorrhage, can be associated with loss of a great portion of functioning renal tissue as a consequence of renal infarction. It is important to note that in some individuals, the posterior segmental artery supplies as much as 50% of the renal parenchyma [28].

In addition to the 6.2% of vessels that had a direct dorsal relationship with the UPJ by crossing it just at the posterior surface, another 20.5% of endocasts were characterized by a vessel crossing less than 1.5 cm above the dorsal surface of the UPJ (Figure 6.47). This is of great importance to surgeons who perform endopyelotomy, because to achieve a patent UPJ it is generally necessary to extend the endoscopic incision into the healthy tissue for 1–2 cm on each side (above and below) of the UPJ stenotic zone. This means that the risk of injury to a dorsal vessel is especially high in posterior and posterolateral incisions.

Furthermore, the risk of injury to a vessel that crosses less than 1.5 cm above the UPJ is particularly high in cases of extensive fibrosis and scarring tissue at the UPJ, because under such circumstances, it is necessary to make a long incision, sometimes extending into the renal parenchyma [45, 60]. Therefore, *posterior and posterolateral incisions at the UPJ must be avoided.*

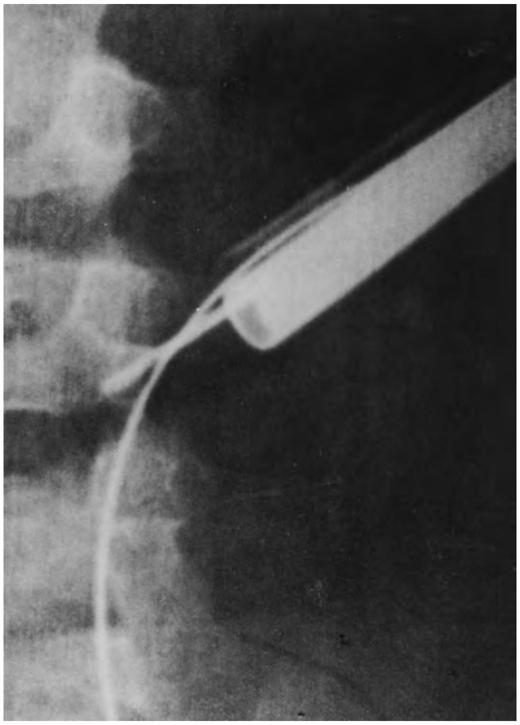

Figure 6.49 Cutting surface of a Sacks knife positioned laterally under fluoroscopic guidance during endopyelotomy.

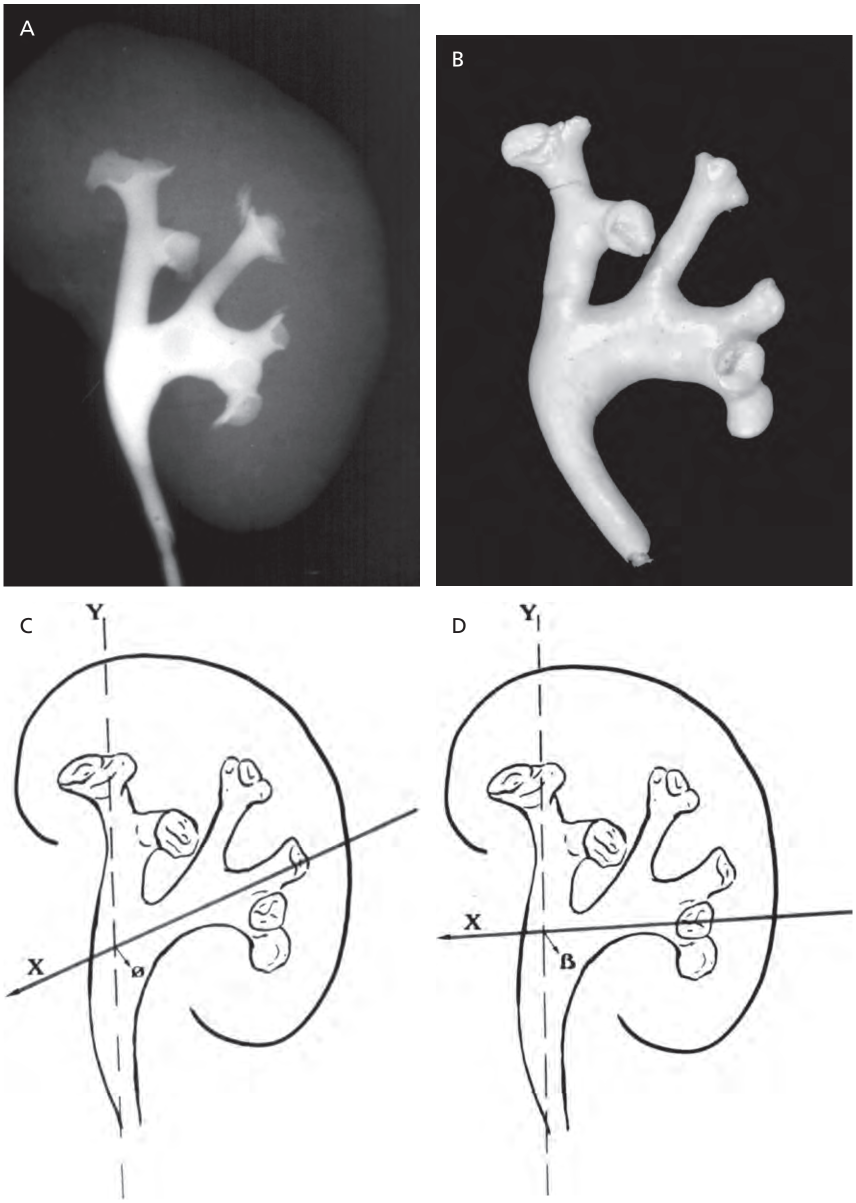

Figure 6.50 (A) Anterior view of a retrograde pyelogram of a left kidney. (B) Anterior view of a three-dimensional polyester resin corrosion endocast of the kidney in A. (C) Schematic of an anterior view of this pelviocalyceal system showing an access through an inferior pole calyx whose infundibulum forms an angle of greater than 90° (obtuse angle) with the ureteropelvic junction (UPJ). Y, first line drawn linking the central axis of the superior ureter with the central axis of the UPJ; X, second line drawn considering the central axis of the calyceal infundibulum chosen for intrarenal access. In this case, the angle formed (θ) measured 111°. This angle would allow easy frontal visualization of the UPJ. (D) Another inferior pole calyx in the same kidney forms a less obtuse angle (θ = 92°) but would still allow frontal visualization of the UPJ for percutaneous endopyelotomy.

Incision at the ureteropelvic junction stenosis based on the vascular anatomy

We recommend that the deep incision alongside the UPJ stenotic wall be performed *just laterally* (Figure 6.48). An incision at this site, which we have called the "nonvascular area" of the UPJ, avoids all important vessels that can be related anteriorly, posteriorly, or less than 1.5 cm above the posterior surface of the UPJ [44, 45, 60].

Even in cases of extensive scar tissue at the UPJ and in cases of vessels that were transposed posteriorly in an earlier dismembered pyeloplasty, the lateral incision in the "nonvascular area" of the UPJ is safe and avoids preoperative angiographic examinations. Also, an unsuspected polar inferior artery crossing anteriorly or posteriorly at the UPJ [47, 61] will be protected from injury.

Maintaining complete anatomic orientation under endoscopic vision is sometimes difficult. Consequently, it is our practice and recommendation to position the cutting instrument laterally and under fluoroscopic guidance (Figure 6.49) before starting the incision at the UPJ. Such a maneuver assures the surgeon that the incision will be made precisely in the lateral aspect, "the nonvascular area" of the UPJ [49, 60, 62].

Intrarenal anatomy for percutaneous access to the ureteropelvic junction

For percutaneous endopyelotomy, a puncture through an upper pole or a midzone calyx is usually recommended to establish a nephrostomy tract and to visualize directly the UPJ to be incised [36, 63, 64]. Although

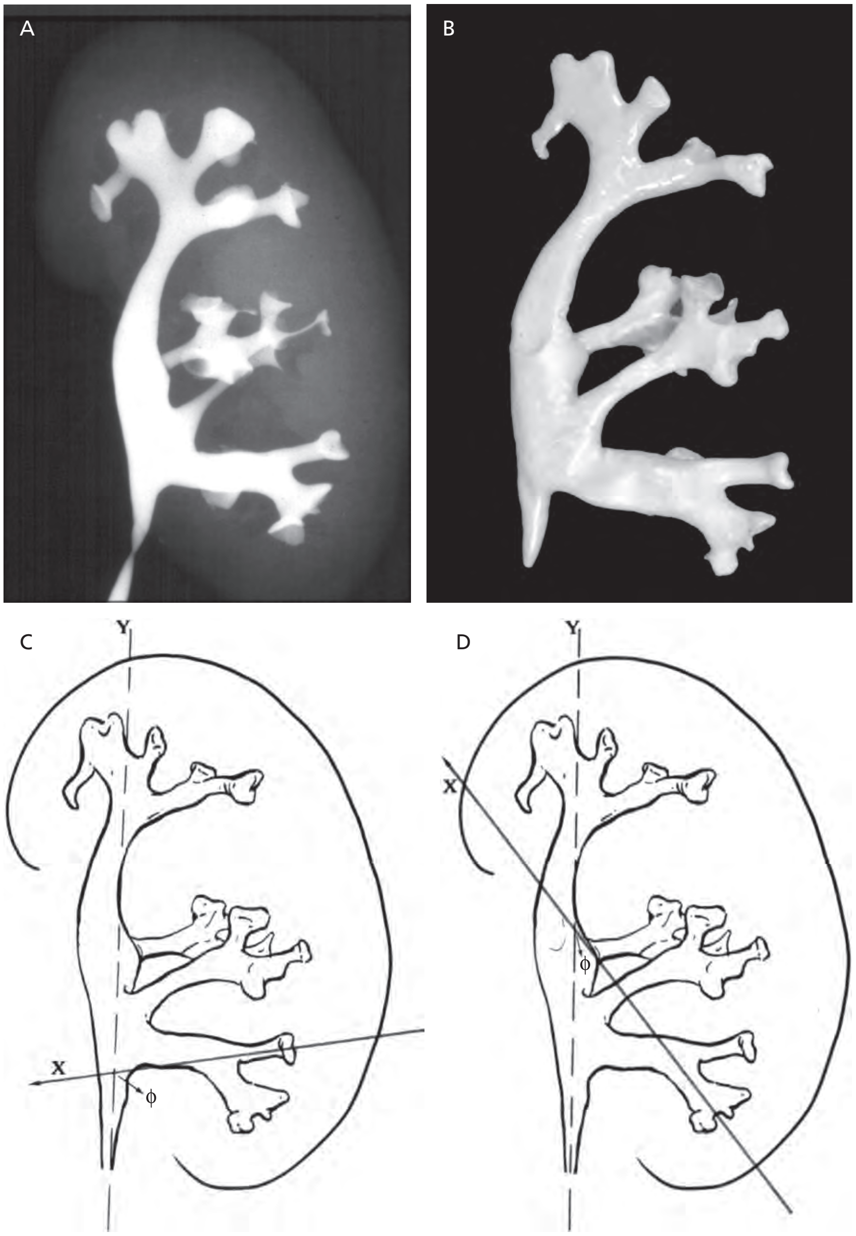

Figure 6.51 (A) Anterior view of a retrograde pyelogram of a left kidney. (B) Anterior view of a three-dimensional polyester resin corrosion endocast of the kidney in A. (C) Schematic of an anterior view of this pelviocalyceal system showing an access through an inferior pole calyx whose infundibulum forms an angle of greater than 90° (obtuse angle) with the ureteropelvic junction (UPJ). Y, first line drawn linking the central axis of the superior ureter with the central axis of the UPJ; X, second line drawn considering the central axis of the calyceal infundibulum chosen for intrarenal access. In this case, the angle formed (θ) measured 98°. This angle would allow easy frontal visualization of the UPJ. (D) Another inferior pole calyx in the same kidney forms an acute angle (θ = 38°) and would not allow frontal visualization of the UPJ for percutaneous endopyelotomy.

a supracostal approach provides an excellent access to the UPJ, this is at the cost of an increased risk of perforation of pleural and adjacent organs [4]. In our experience and based on the collecting system anatomy, *in patients without previous renal surgery*, we found that an upper pole puncture is rarely necessary. Also, a midzone puncture is necessary in only one-third of cases. In most patients, an access through a lower pole calyx enables a frontal visualization of the UPJ [65]. *The calyx should be selected based on the angle that is formed between the calyceal infundibulum and the UPJ.*

How to determine the angle

For evaluation of the angle, two lines must be drawn. The first line (y-axis) must link the central axis of the superior ureter to the central axis of the UPJ. The second line (x-axis) is the central axis of the calyx being considered for puncture (Figures 6.50–6.52).

The angle formed by the intersection of the lines is measured with a protractor (Figures 6.50–6.52). In clinical practice, however, we have found that it can be simply deduced whether the angle is larger or

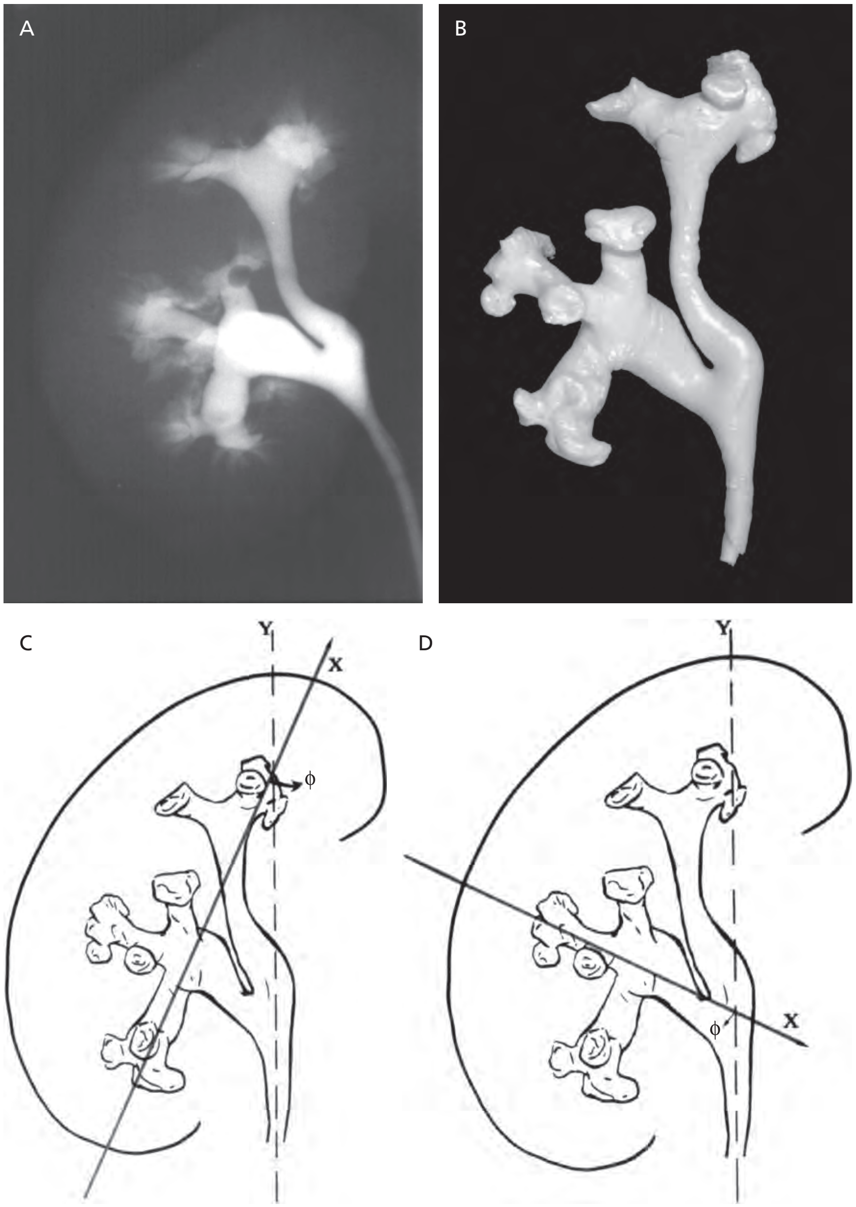

Figure 6.52 (A) Anterior view of a retrograde pyelogram of a right kidney. (B) Anterior view of a three-dimensional polyester resin corrosion endocast of the kidney in A. (C) Schematic of an anterior view of this pelviocalyceal system showing an access through an inferior pole calyx whose infundibulum forms an angle of greater than 90° (obtuse angle) with the ureteropelvic junction (UPJ). Y, first line drawn linking the central axis of the superior ureter with the central axis of the UPJ; X, second line drawn considering the central axis of the calyceal infundibulum chosen for intrarenal access. In this case, the angle formed (θ) measured 24°. This angle would probably render a frontal visualization of the UPJ impossible for performing percutaneous endopyelotomy. (D) Access though a midzone calyx whose infundibulum forms an obtuse angle (θ = 116°) and would allow easy frontal visualization of the UPJ for percutaneous endopyelotomy, without requiring a superior pole puncture.

smaller than 90° by examining the intersection of the lines.

How to select a calyx for puncture

An appropriate calyx can be chosen based on the angle that is formed between the calyceal infundibulum and the UPJ. If the chosen calyx forms an angle equal to or greater than 90° to the UPJ, the intrarenal access through this calyx will permit an easy and frontal visualization of the UPJ (Figure 6.53). Our anatomic studies showed that in around 70% of the cases, it is possible to find at least one posterior lower calyx whose infundibulum forms an angle greater than 90° to the UPJ.

The angle formed between the UPJ and the calyceal infundibulum must be determined for the chosen calyx, because the angle will vary for different calyces in the same region of the kidney, greater than 90° in some (98°in Figure 6.51C), and smaller than 90° in others (38° in Figure 6.51D). Therefore, by selecting an appropriate calyx based on analysis of the angle, it is possible to access the UPJ through a lower calyx in most cases.

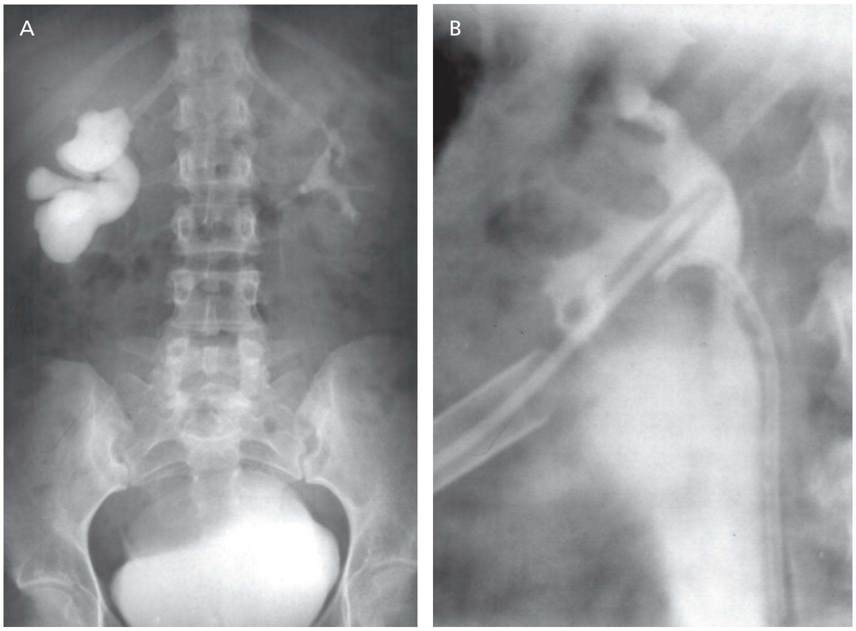

Figure 6.53 (A) Intravenous pyelogram from a 30-year-old woman shows a ureteropelvic junction (UPJ) obstruction with a dilated pelviocalyceal system. (B) Pyelogram performed through the nephrostomy tube immediately after endopyelotomy reveals contrast extravasation through the incision in the UPJ. The Amplatz sheath is being withdrawn. The endopyelotomy was easily performed through an inferior pole calyx.

In some cases (around 30%), it is necessary to puncture a midzone calyx, because in these cases all lower calyceal infundibula form angles smaller than 90° with the UPJ (Figure 6.52). We found at least one midzone calyx forming an angle equal to or greater than 90° with the UPJ in 208 pelviocalyceal systems [65].

In cases with a history of previous open surgery, or even percutaneous surgery, access through a midzone calyx must be considered, because there is a high possibility of perinephric scarring. Depending on the pelviocalyceal anatomy, a middle calyx puncture will offer easier access to the UPJ, avoiding the need for excessively inclining the scarred kidney, a maneuver that would result in intrarenal damage and bleeding [66].

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CHAPTER 7

Pathophysiology of Urinary Tract Obstruction

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Introduction

We have been involved with research on the pathophysiology of unilateral (UUO) and bilateral ureteral obstruction (BUO) for the last 25 years. When we first began in this field the literature on the effects of UUO and BUO on the kidney focused mainly on the glomerulus and tubular function. The progression of the vasodilation and subsequent vasoconstriction of the afferent and efferent glomerular arterioles and the ultimate effect this had on renal blood flow, the glomerular filtration rate, and tubular function were initially reported. At that time, measuring effective renal blood flow (eRBF) and inulin clearance, along with the usual parameters of tubular function, would be ample information to report.

This progressed to reporting more information on the hormones, peptides, eicosanoids, and other vasoactive mediators that were circulating, and the effect they had on the intraglomerular vasculature and overall RBF, glomerular filtration, and tubular function.

The focus now is the interstitium, the space between the tubules. UUO is accompanied by changes in the architecture of the kidney. The most prominent interstitial change is fibrosis, and the accumulation of collagens and other extracellular matrix components. Interstitial fibrosis is characteristic of many clinical entities, including diabetes, ureteral obstruction, transplant rejection, and glomerulonephritis. It has been shown in a variety of chronic renal diseases that the presence of interstitial fibrosis is a major determinant of glomerular filtration rate (GFR). Therefore, an understanding of the processes leading to fibrosis could eventually lead to targeted antifibrotic strategies that could allow patients to regain their lost renal function.

In this chapter, we will explore some of the time-tested and older information on the effects of UUO and BUO on the renal glomerulus and tubule. We will present some of the newer concepts regarding the cellular and molecular mechanisms in the development of renal fibrosis. While the information presented will expose the reader to the basics of this information, it will not be a comprehensive review of the subject (for recent reviews, see [1, 2]).

Patient presentation

Symptoms

Urinary tract obstruction can result in a wide range of symptoms, from asymptomatic (incidentally discovered) to the classic picture of renal colic. The symptom complex varies according to (1) the time interval over which the obstruction occurs (i.e. acute or chronic); (2) whether the obstruction is unilateral or bilateral; (3) the etiology of the obstruction (i.e. intrinsic vs extrinsic); and (4) whether the obstruction is complete or partial.

Acute obstruction is usually associated with flank pain that may radiate into the groin and/or ipsilateral thigh. Patients commonly experience nausea, vomiting, and chills. If the renal unit is infected, high fevers may also be present. A patient with high fever, above 101°F, requires emergent urologic intervention and relief of the obstruction. It is more common to have acute UUO than BUO; however, if acute BUO occurs, the patient also

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may experience a sudden onset of anuria. UUO and BUO can develop over long periods of time, in which case patients are usually asymptomatic, making the diagnosis of obstruction more difficult and, in many cases, incidental. When the obstruction is bilateral and chronic, patients may present with nonspecific complaints of an increase in abdominal girth (pants do not fit), ankle edema, malaise, anorexia, headaches, weight gain, fatigue, and shortness of breath. They may also have symptoms reflective of uremia, such as mental status changes, tremors, and gastrointestinal bleeding. Patients with either a solitary kidney or a nonfunctioning contralateral renal unit can present with UUO and symptoms of uremia.

When the obstruction is unilateral and chronic, the patient may complain of intermittent flank pain during periods of forced diuresis, such as after the consumption of alcohol, a known diuretic. This has been referred to as a Dietl's crisis, after the Polish physician, Joseph Dietl. Classically, the pain is described as a sudden excruciating pain in the kidney caused by distention of the renal pelvis, rapid ingestion of large amounts of liquid, or kinking of a ureter that produces temporary occlusion of the flow of urine from the kidney. If there is hydronephrosis associated with blunt trauma, the presenting symptom can also be gross hematuria. The extrinsic causes of obstruction usually have a more insidious and hence symptom-free presentation, whether they are unilateral or bilateral. These obstructions are usually detected incidentally during the routine clinical work-up of the primary disease process.

A history of the patient's voiding habits is also significant. These can vary from symptoms of a weak and intermittent urine stream, urgency, urgency incontinence, overflow incontinence, and nocturia, to barely any urination at all (i.e. complete obstruction). Finally, patients may also notice rather profound increases in their urine output, out of proportion to their fluid intake, which results from poor renal concentrating ability.

Clinical signs and biochemical findings

The clinical signs of urinary tract obstruction are somewhat nonspecific. Obstruction is occasionally associated with an abdominal mass, usually suprapubic, but it may also be a large flank mass, palpable during physical examination, which on rare occasions can be visible. The patient may also have signs of volume overload, such as bipedal edema, pulmonary congestion, and hypertension. Laboratory data may include hematuria (microscopic and/or gross), proteinuria, crystalluria, pyuria, and urinary casts. When chronic obstruction is the predominant clinical picture, the urinary diagnostic indices are most often similar to those seen with acute tubular necrosis: an elevated urinary sodium concentration, a decreased urine osmolality, and a decreased urine-to-plasma creatinine ratio. If the obstruction is more acute and not accompanied by renal failure, the urinary indices can resemble those of prerenal azotemia: a low urinary sodium concentration and an increased urine osmolality [3]. The serum chemistry studies may demonstrate elevations of serum blood urea nitrogen (BUN) and creatinine, hyperkalemia, and acidosis.

When patients experience acute obstruction in the presence of bacterial urinary tract infection, they may present with signs and symptoms of pyelonephritis or systemic sepsis. Obstruction coexisting with infection is a true urologic emergency, and appropriate imaging studies (excretory urogram, renal ultrasonography or retrograde ureteropyelography) must be performed on an emergency basis. The obstruction must be relieved by either percutaneous nephrostomy or a ureteral stent.

The rationale for immediate relief of obstruction is based upon the physiology of fluid reabsorption during obstruction. After the onset of obstruction there is increased intrapelvic pressure, resulting in pyelolymphatic and pyelovenous urine back flow as well as possible fornix rupture and extravasation [4, 5]. Accordingly, there is direct movement of urine and bacteria into the vascular tree during obstruction, resulting in a life-threatening situation. In chronic obstruction, despite a marked reduction in GFR and RBF [6], urine continues to move into the vascular system [7].

Diagnosis

Excretory urography

For the urologist, the intravenous urogram (IVU) has been the gold standard for the detection of ureteral obstruction in patients with normal renal function and who have no allergies to contrast material and are not pregnant. The urogram can provide both functional and anatomic details of the obstruction, as opposed to ultrasonography, which provides more anatomic detail.

Acute urinary obstruction is visualized on the IVU by (1) the obstructive nephrogram; (2) a delay in filling of the collecting system with contrast material; (3) dilation of the collecting system, possibly with an increase in renal size; and (4) possible forniceal rupture with urinary extravasation [8].

Chronic cases of ureteral obstruction are usually visualized by ureteral dilation, tortuosity, and a standing column of contrast in the ureter to the point of obstruction. The kidney may demonstrate marked parenchymal thinning (either segmental or complete), calyceal crescents, and the soap bubble nephrogram [8]. However, the IVP is rarely performed today in radiology departments. It has essentially been replaced by the unenhanced CT scan (see below).

Ultrasonography

The renal sonogram is a good starting point for evaluating the renal units of patients who have azotemia, contrast -induced allergy, are pregnant, or are in the pediatric age group. Significant information can be obtained about both the renal parenchyma and the collecting system with no exposure to radiation, or contrast-induced nephrotoxicity or anaphylaxis.

Hydronephrosis will appear as a dilated collecting system separating the normally echogenic renal sinus, creating an anechoic central area surrounded by parenchyma. Echoes within the collecting system may indicate an infection (pyonephrosis), hemorrhage, or a lesion of the transitional mucosa, among other diagnoses. The thickness of the renal parenchyma can be measured as an indicator of the duration of the obstruction; the degree of hydronephrosis should not be equated with the duration of the obstruction.

There are several pitfalls to the use of ultrasonography for diagnosing obstruction. Both the underdiagnosis of hydronephrosis, i.e. missing an obstruction (false negative), and overdiagnosis of obstruction due to the presence of hydronephrosis (false positive) are possible. Sonograms can be false negative as a result of an acute onset of obstruction, an intrarenal collecting system, dehydration, and the misinterpretation of caliectasis for renal cortical cysts. Sonograms can be false positive for obstruction as a result of a capacious extrarenal pelvis, parapelvic cysts, vesicoureteral reflux, and a high urine flow state [8]. Therefore, although an excellent tool for the initial evaluation of selected patients with suspected renal obstruction, the sonogram should be interpreted carefully and must be consistent with the overall clinical picture.

Diuretic renography

The diuretic renogram is becoming more widely utilized than excretory urography for evaluation of the dilated collecting system. It provides a noninvasive measure of the relative renal function and has the ability to wash out the radiopharmaceutical agent from the dilated collecting system. There is a marked reduction in radiation dose in comparison with excretory urography, and there is no potential for contrast-induced nephrotoxicity [9].

The most widely used radiopharmaceutical agents are: (1) tubular tracers: ^{131}I-ortho-iodohippurate (OIH) and ^{99m}Tc-mercaptoacetyltriglycine (MAG3); and (2) glomerular tracers, namely ^{99m}Tc-diethylene triaminepenta-acetic acid (DTPA). For evaluating obstruction, the radiopharmaceutical agent of choice today is MAG3, because it is more efficiently extracted by the kidney than is DTPA, delivers a lower dose of radiation to the obstructed kidney than does OIH, and is excreted by the same portion of the tubule that responds to furosemide [9, 10]. MAG3 has been shown to provide better counting statistics and visualization of the anatomy of obstruction than do OIH and other radiopharmaceutical agents [11].

The technique of patient preparation and the timing of the administration of the diuretic, when diuretic renography is performed, are extremely important. The patients should be well hydrated before the procedure. An intravenous line may be started before the procedure [9, 12]. Patients who can void spontaneously do not require bladder catheterization. Those who cannot void spontaneously do require bladder catheterization to: (1) ensure adequate bladder drainage; (2) reduce false-positive results; and (3) decrease the radiation dose to the bladder and gonads. The patient's renal function is extremely important when the results from a diuretic renogram are interpreted. In the presence of a reduced creatinine clearance, it may be necessary to increase the diuretic dose to achieve an adequate flow rate and reduce the possibility of a false-negative result [13].

The timing of the administration of the diuretic after the administration of the radiopharmaceutical agent has been carefully worked out. Brown *et al*. determined that the urinary flow rate is 3.5 mL/min greater at 15–18 min after intravenous furosemide than at 3–6 min after a diuretic (Figure 7.1) [14]. The traditional diuretic renogram is performed by administering the radiopharmaceutical agent and obtaining images, followed 20 min later by intravenous administration of the diuretic, and then measuring the half-life for the clearance of the tracer from the collecting system. O'Reilly *et al*. referred to this technique as the F + 20 diuretic renogram [15, 16]. Figure 7.2 depicts the various outcomes from the F + 20

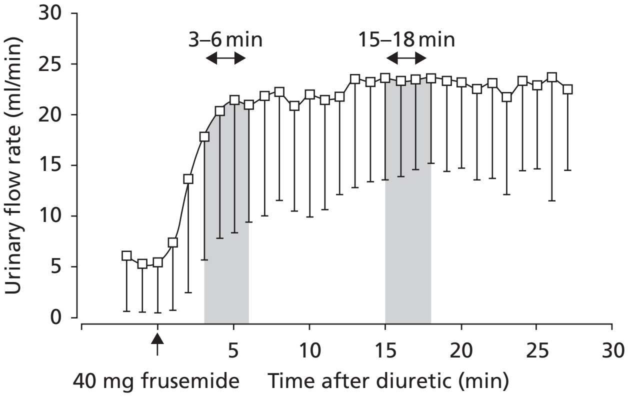

Figure 7.1 Mean urinary flow rates following diuretic injection (error bars indicate standard deviation) (reproduced from Brown *et al. B J Urol* 1992;69:121–125, with permission).

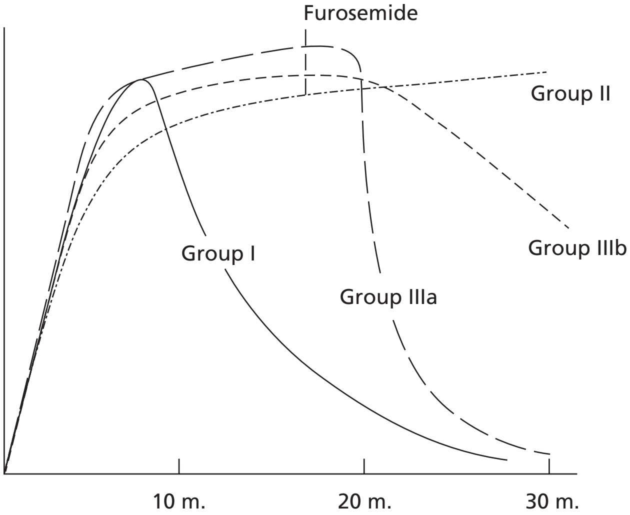

Figure 7.2 Gamma camera renograms obtained from computer generated regions of interest using ^{123}I-ortho-iodohippurate (OIH) demonstrate four responses. Group I is a normal renogram. Since obstruction is sometimes unmasked by diuretic administration, O'Reilly *et al.* recommend a repeat renogram 15 min after diuretic administration. A second group I, normal renogram, excludes obstruction. Progressive accumulation (group II) despite administration of furosemide at about 20 min after tracer injection confirms obstruction. On the other hand, rapid emptying following diuretic administration (group IIIA) despite an initial rise in the renogram curve indicates dilation without obstruction. Finally, an increasing curve with a partial excretory response may indicate either partial obstruction or renal dysfunction with an inability to respond to the diuretic (group IIIB) (reproduced from O'Reilly, P.H., Shields, R.A., Testa, J.H., eds. *Nuclear Medicine in Urology and Nephrology*, 2nd edn. London, England, Butterworths, 1986, pp, 91–108, with permission).

diuretic renogram. Diagnostic dilemma arises with patients who show a partial excretory response; this indicates either an inability to excrete the radioisotope because of poor renal function or a truly partially obstructed system (Group IIIa in Figure 7.2). Upsdell *et al*. were able to convert this equivocal response to the diuretic into a wash-out response by administering the diuretic 15 min before administering the radiopharmaceutical agent, i.e. F – 15 [13]. This is the time it takes for lasix to reach its maximal diuretic effect and thus eliminates "lag-time" as a false positive for obstruction. Some centers routinely use the F – 15 technique for diuretic renography when renal obstruction is suspected. Others use the F + 20 technique for their routine diuretic renograms, reserving the F – 15 technique for use when the F + 20 method demonstrates partial obstruction.

Data from the diuretic renogram can be interpreted either visually or by quantitative measurements of the half-life of the diuretic response [12]. There are many factors that influence the half-life, including: (1) renal function, which includes the level of renal maturity; (2) compliance of the collecting system; (3) volume of the collecting system; (4) hydration of the patient; (5) presence or absence of a bladder catheter; (6) radiopharmaceutical agent; and (7) dose of the diuretic [9, 17]. It is generally accepted that a clearance of the radiopharmaceutical agent from the renal pelvis with a half-life of less than 10 min is normal; some experts consider a half-life of less than 15 min to be normal. Clearance of tracer with a half-life between 15 and 20 min is considered equivocal and a half-life greater than 20 min indicates an obstruction [9, 18].

Whitaker test

The Whitaker test was considered the gold standard for the evaluation of upper urinary tract dilation. It provided urodynamic evidence of a mechanical obstruction of the upper urinary tract at a given flow rate. With the advent of the diuretic renogram and some of the newer radiopharmaceutical agents, the Whitaker test is not often utilized clinically. The Whitaker test is performed with the patient placed on a fluoroscopy table in the prone position. Before the patient is positioned prone, a bladder catheter is placed and connected to a pressure transducer for continuous monitoring of intravesical pressures with changes in renal pressure. A renal cannula (18G) is then inserted and connected to a pressure transducer. A combination of saline and contrast is administered via the renal cannula at a rate of 10 mL/min. Bladder pressure is monitored throughout the procedure and its relationship to changes in renal pressure can be significant. Contrast is given along with the saline, making fluoroscopic monitoring of the anatomic site of the obstruction possible [19].

Results are separated into three categories [20]:

- Pressure less than 15 cmH_2O = nonobstructed;
- Pressures of 15–22 cmH_2O = equivocal;
- Pressures greater than 22 cmH_2O = obstructed.

Because the diuretic renogram is noninvasive and easily reproducible, and provides quantitative evaluation of the split and total renal function with minimal radiation exposure, it is clinically utilized more today than the Whitaker test. However, when there is extreme upper tract dilation and/or poor renal function precluding an adequate diuretic response, the pressure flow study may still have clinical utility.

Duplex Doppler ultrasonography and renal resistive index

The use of duplex Doppler during ultrasonographic evaluation of the kidney allows the determination of the renal resistive index (RI) where [21, 22]:

RI = ([peak systolic velocity]
− lowest diastolic velocity])/
[peak systolic velocity]

A value of 0.70 has been taken as the upper limit of normal [23]. RIs above 0.70 are used for the diagnosis of obstruction, although this diagnosis is not exclusive for obstruction, in as much as medical renal diseases alone can also cause the RI to exceed 0.70. An RI in the obstructed kidney that is 0.1 greater than the RI in the contralateral kidney is considered to be significant enough to indicate obstruction [24].

There is much controversy in the literature regarding the use of the RI in obstruction. Platt *et al*. presented data on 23 patients with acute UUO of 36-h duration or less, measuring the RI index in the "obstructed" and the contralateral renal units [25]. The mean RI in the obstructed kidney was 0.77, as opposed to 0.60 for the normal contralateral kidney. In three obstructed kidneys with an RI of less than 0.70, two had pyelosinus extravasation and one had obstruction for less than 4–5 h. Because the vasoconstriction of UUO occurs after 5–6 h, the RI may not rise until renal obstruction has been present for at least 5–6 h. Platt *et al*. concluded that Doppler determination of renal RIs is a valuable addition for improving the accuracy of routine renal ultrasonography in the diagnosis of renal obstruction in patients presenting with acute renal colic and for whom an IVU is not desirable, e.g. pregnant patients and patients with a history of contrast-induced allergy or renal failure.

Other investigators believe there is no role for duplex Doppler sonography in the detection of acute renal obstruction [22, 26]. Tublin *et al*. evaluated 32 patients with acute renal colic [26]. Twelve of the obstructed kidneys had a mean RI of less than 0.70, and seven of the nonobstructed kidneys had a mean RI of greater than 0.70. Using an RI of greater than 0.70 as diagnostic of acute renal obstruction, they determined that the sensitivity and specificity of duplex Doppler sonography were 37% and 84%, respectively. When using a difference in the RI of greater than 0.10 between the ipsilateral and contralateral renal units to diagnose obstruction, they determined that the sensitivity and specificity were 37% and 100%, respectively.

The difference in clinical findings between the two studies described above may result from several factors, including: (1) the quality of the examination and the Doppler waveform analysis; (2) the duration of obstruction; (3) the presence of a fornix rupture and extravasation; and (4) the degree of obstruction. Finally, Tublin *et al*. pointed out that the initial management of the acute renal colic with nonsteroidal anti-inflammatory drugs (NSAIDs) could alter the intrarenal vascular tone and hence affect the RI [26].

Computed tomography and magnetic resonance imaging

Computed tomography (CT) is an alternative to IVU for patients in whom the immediate use of intravenous contrast without steroid preparation is contraindicated, e.g. patients with allergy to iodinated contrast or shellfish, and patients with asthma, or in patients with elevations in serum BUN and/or creatinine.

Smith *et al*. investigated the use of noncontrast-enhanced CT in the diagnosis of acute flank pain [27]. They compared the findings in 20 patients with acute flank pain on both noncontrast-enhanced CT and IVU. CT and IVU demonstrated ureteric obstruction in 12 patients. In five of the 12, a stone was demonstrated on both studies. Six patients had a stone that was seen on noncontrast-enhanced CT and not on IVU. In one patient, a stone could not be visualized on either study, and no obstruction was demonstrated with either investigation in eight patients. Noncontrast-enhanced CT was performed at either 5- or 10-mm cuts, and all studies were completed within 5 min. Noncontrast-enhanced CT is more sensitive than IVU in the detection of ureteric stones in acute flank pain ($P < .01$). In addition, CT can provide information about extrinsic causes of ureteral obstruction, as well as nonurinary causes for the acute flank pain. Therefore, the patient who is not a candidate for IVU in the emergency room, and yet warrants a diagnosis for flank pain, may be a candidate for noncontrast-enhanced CT scan.

Today, unenhanced helical CT is gaining widespread acceptance in many institutions over conventional CT imaging. The images are obtained faster than conventional CT scanning, often in one breath hold. The axial images can be used to create sagittal and/or coronal reformations, adding to the anatomic detail of the urinary tract and the potential for stone passage. The secondary signs of obstruction on helical CT include: (1) hydroureter; (2) perinephric stranding; (3) hydronephrosis; (4) periureteral edema; and (5) renal swelling [28]. Unenhanced helical CT and conventional CT may not differentiate a uric acid from a calcium stone, necessitating a kidney–ureter–bladder (KUB) X-ray study to differentiate the stone type. However, it has been described that uric acid calculi have lower attenuation values than calcium oxalate calculi, which have very high attenuation values (1000–1570 Hounsfield units). Therefore, the differentiation of stone type is possible on the CT images [28]. It should be noted that stones formed following administration of indinavir (Crixivan) are not detectable on CT [29].

Rothpearl *et al*. investigated the use of magnetic resonance imaging (MRI) for the simultaneous visualization of the entire urinary tract without the use of intravenous contrast or ionizing radiation [30]. For all patients with urinary tract obstruction, a diagnosis of obstruction was made on the MR urogram. However, in eight patients in whom ureteral calculi was the source of obstruction, there was no visualization of calculi on the MR urogram. This was accomplished by comparing the urogram with a scout radiograph of the kidneys, ureter, and bladder. The point of obstruction was identified in all patients, and other etiologies for obstruction, e.g. intraluminal ureteral neoplasm and ureteral stricture disease, were well visualized. The disadvantages of this technique, in addition to the inability to identify the ureteral calculus, are the image acquisition time of 34 min and the cost of the procedure. Again, for patients with allergies to iodinated contrast and renal failure, this technique may have its place.

Ureteral obstruction

There are a host of diseases that can cause either UUO or BUO (Table 7.1). Most are well known to the urologist.

The experimental models for ureteral obstruction include: (1) unilateral or bilateral ureteral ligation; (2) burying the mid ureter within the psoas muscle; and (3) placing silastic plastic tubing around the ureter to constrict the ureteral lumen.

Unilateral ureteral obstruction

Renal blood flow, glomerular filtration rate, and ureteral pressure

The acute unilateral occlusion of a ureter will result in a characteristic triphasic relationship between RBF and ureteral pressure [31]. The first phase is characterized by a rise in both ureteral pressure and RBF lasting approximately 1–1.5 h. This is followed in phase 2 by a decline in RBF and a continued increase in ureteral pressure lasting until the fifth hour of occlusion. The final phase ensues with a further decline in RBF accompanied by a progressive decrease in ureteral pressure (Figure 7.3). Hemodynamically, phase 1 is characterized by an initial afferent arteriole vasodilation [6] followed by an efferent arteriole vasoconstriction in phase 2 and afferent arteriole vasoconstriction in phase 3 [32]. The third phase of UUO, the vasoconstrictive phase, is characterized by both pre- and post-glomerular vasoconstriction that reduces both RBF and ureteral pressure [31]. Yarger *et al*. demonstrated a marked decrease in the perfusion of the superficial cortical tissue and an increase in the perfusion of juxtamedullary glomeruli after 24 h of UUO [33]. In addition, effective renal plasma flow (eRPF) was shown to be 55% of control values in the obstructed kidney after 24 h of UUO [34]. Utilizing the injection of microspheres during ureteral occlusion, they also demonstrated an increase in intrarenal blood flow to the juxtamedullary nephrons, with a corresponding decrease in blood flow to the outer cortical nephrons. They believed that an increase in renin in the outer cortex relative to the inner medulla may explain the shift in intrarenal blood flow [34]. Glomerular cast studies show the poor glomerular perfusion that accompanies UUO (Figure 7.4). Arendshorst *et al*. confirmed with micropuncture studies that changes seen in the whole kidney by 24 h of UUO are found at the single nephron level in association with afferent arteriolar vasoconstriction [35]. Studies using a continuous infusion of 51-chromium-ethylenediamnietetra-acetic acid (^{51}Cr-EDTA), which allow direct measurement of GFR during obstruction, show a 75% decrease in GFR after the onset of UUO [36].

The initial increase in RBF, which has been well characterized in the dog and rat [37], may not occur in all species. In studies in the pig, which has a multicalyceal kidney similar to humans, there is a continuing decline in RBF after onset of UUO [36]. In baboons, 12 h of UUO was not accompanied by a significant change in RBF [38]. In the 4-week old lamb, RBF was stable for 5 h after onset of UUO, and declined to 71% of baseline at 5 days [39]. It is not known if the difference in the RBF response is due to the presence of a multicalyceal kidney or other factors.

Although the physiologic changes characteristic of phase I and III of UUO have been known for some time, studies are still underway to understand the underlying cellular and molecular changes. Early studies invoked local physical interactions to explain changes in afferent and efferent arteriolar tone. Table 7.2 summarizes the effects of the various mediators on afferent and efferent glomerular arteriolar tone. However, it soon became clear that biochemical mediators were responsible for a substantial portion of these changes. Numerous studies have been carried out to determine the role of eicosanoids (prostaglandins and thromboxane), angiotensin II, nitric oxide, and endothelin in the acute and chronic changes in RBF.

Tubular changes

Several studies suggested that the increased excretion of water and salt after UUO occurs in either deep nephrons or the collecting duct of superficial nephrons [40–42]. However, Buerkert *et al*. were able to show with micropuncture studies that the collecting duct's ability for reabsorption and its permeability to water were not altered by acute ureteral occlusion [43]. Therefore, the more likely location for the increased sodium excretion is the deep juxtamedullary nephron.

Jaenike and Bray were able to produce a concentrating defect in the unilaterally obstructed kidney after only 6

Table 7.1 Possible causes of obstructive nephropathy.

Renal	
Congenital	Polycystic kidney Renal cyst Fibrous obstruction at uteropelvic junction Peripelvic cyst Aberrant vessel at uteropelvic junction
Neoplastic	Wilms' tumor Renal cell carcinoma Transitional cell carcinoma of the renal pelvis Multiple myeloma
Inflammatory	Tuberculosis Echinococcus
Metabolic	Calculi
Miscellaneous	Sloughed papillae Trauma Renal artery aneurysm
Ureter	
Congenital	Stricture Ureterocele Ureterovesical reflux Ureteral valve Ectopic kidney Retrocaval ureter Prune belly syndrome
Neoplastic	Primary carcinoma of ureter Metastatic carcinoma
Inflammatory	Tuberculosis Schistosomiasis Abscess Ureteritis cystica Endometriosis
Miscellaneous	Retroperitoneal fibrosis Pelvic lipomatosis Aortic aneurysm Radiation therapy Lymphocele Trauma Urinoma Pregnancy
Bladder and urethra	
Congenital	Posterior urethral valve Phimosis Urethral stricture Hypospadias and epispadias Hydrocolpos
Neoplastic	Bladder carcinoma Prostate carcinoma Carcinoma or urethra Carcinoma of penis
Inflammatory	Prostatitis Paraurethral abscess
Miscellaneous	Benign prostatic hypertrophy Neurogenic bladder

min of ureteral occlusion [44]. Kessler demonstrated a concentrating defect in the obstructed kidney within 5–8 min of ureteral occlusion [45]. The administration of large doses of antidiuretic hormone (ADH) restored the concentrating ability and the papillary chloride concentration in saline-loaded animals. This observation is contrary to that of other investigators, who have found the concentrating defect in the ipsilateral kidney of UUO to be ADH resistant. Solez *et al*. observed a marked decrease in urine osmolality in dehydrated rats after

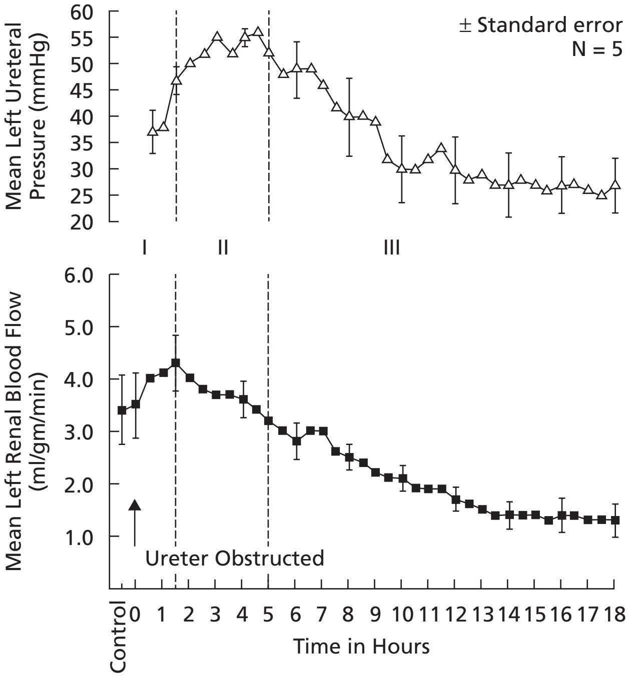

Figure 7.3 Triphasic relationship between ipsilateral renal blood flow and left ureteral pressure during 18 h of left occlusion. The three phases are designated by Roman numerals and divided by vertical dashed lines. In Phase I, renal blood flow (RBF) and ureteral pressure rise together. In Phase II, the left RBF begins to decline; ureteral pressure remains elevated and, in fact, continues to rise. Phase III shows the left RBF and pressure declining together (reproduced from Moody *et al*. [31], with permission).

relief of 18 h of UUO, not in association with a concomitant increase in urine output [46]. They found a significant decrease in inner medullary plasma flow during 18 h of UUO, and the flow increased after the release of ureteral occlusion. Histologic study revealed necrosis of both the inner and outer medullae. This physical effect of obstruction on the medulla may result in a decreased ability of the post-UUO kidney to concentrate urine.

Wilson examined the effect of volume expansion on post-UUO renal function and found a significant increase in free water clearance from the obstructed kidney in association with an increase in urine flow rate [47]. Wilson concluded that volume expansion was enhancing an already-present defect in water reabsorption either in distal nephrons and/or deep nephrons or in collecting ducts of the obstructed kidney. Hanley and Davidson also described an inability of the kidney to concentrate urine after obstruction [48]. This inability was associated with an inability of the cortical collecting tubule to respond to either ADH (vasopressin) or cyclic adenosine monophosphate (cAMP) stimulation; there was a 76% reduction in the response of the collecting tubule to either stimulus. There is an increase in prostaglandin E1 (PGE_1) production with UUO, and it is known that PGE_1 can inhibit the tubular effects of vasopressin, increasing free water losses from the post-UUO kidney [49].

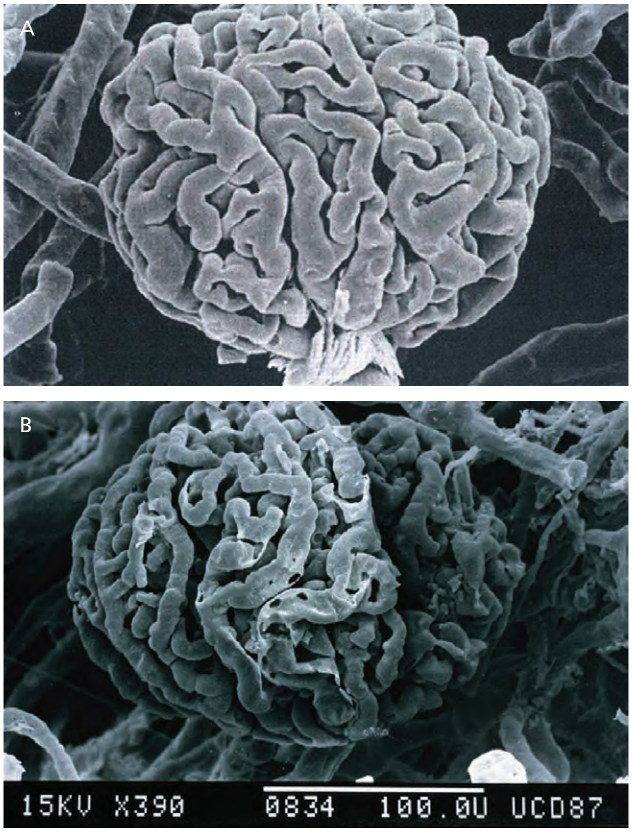

Figure 7.4 (A) Scanning electron microscopic appearance of normal glomerular cast (magnification x 390). (B) Appearance of glomerular microvascular cast after obstruction showing capillary collapse and irregularity (magnification x 390) (reproduced from Leahy *et al*. Renal injury and recovery in partial ureteric obstruction. *J Urol* 1989;142:199–203, with permission).

Table 7.2 Vasoactive mediator involvement in the hemodynamic changes of unilateral ureteral obstruction.

	Afferent arteriole	Efferent arteriole
Vasodilation	Prostaglandin E_2 (PGE_2)	PGI_2
	Prostaglandin I_2 (PGI_2)	NO
	Nitric oxide (NO)	
	Atrial natriuretic peptide (ANP)	
Vasoconstriction	Angiotensin II (AII)	AII
	Endothelin (ET)	ET
	Platelet activating factor (PAF)	PAF
		ANP

The characterization of the aquaporins, a family of membrane water channels, provides a molecular basis for transmembrane water movement [50]. Aquaporin-2 is the predominant vasopressin-sensitive water channel of the collecting duct. Frokiaer *et al*. have examined changes in aquaporin expression in UUO [51]. There was a 77% decrease in aquaporin expression with 24 h of UUO, which persisted for at least 24 h after release of UUO. Consistent with the decreases in aquaporin was a greatly increased free water clearance in the obstructed kidney.

The kidney has an impaired distal hydrogen ion secretion after obstruction. This is seen as a lack of an increase in carbon dioxide partial pressure (PCO_2) during bicarbonate loading, as well as impaired urinary acidification with the administration of sodium sulfate. The postobstruction kidney has a higher bicarbonate reabsorption rate than the contralateral kidney [52]. Walls *et al*. also demonstrated a low urinary PCO_2, during bicarbonate loading, in the post-UUO kidney in comparison with the contralateral kidney, as well as an elevation in urinary pH from the postobstruction kidney [53].

After the release of UUO, the fractional excretion of phosphate is markedly decreased in the obstructed kidney (3.4%), whereas it is increased in the control kidney (35.3%). This is accompanied by a twofold greater fractional excretion of sodium in the obstructed kidney than in the control kidney. However, the decrease in phosphate excretion is believed to be secondary to a decreased filtered load of phosphate. The increased excretion of salt and water is secondary to a decreased reabsorption in the distal nephron without a concomitant decrease in proximal reabsorption [54].

Harris and Yarger described a marked decrease in urinary potassium excretion from the ipsilateral kidney after 24 h of UUO [55]. Yarger and Griffith found a decrease in both the absolute and fractional excretion of potassium after 24 h of UUO with micropuncture studies [33]. This suggests that the decrease in potassium excretion does not result from a decrease in the filtered load of potassium. Explanations for the decrease in potassium excretion would be that the distal tubular volume flow rate is low after UUO, the amount of sodium passing through the distal nephron is also decreased during UUO, and the normal potassium secretory mechanism has been directly interfered with as a result of mechanical obstruction. These explanations are supported by the work of Thirakomen *et al*. who showed a persistent decrease in absolute potassium excretion despite volume expansion or sodium sulfate administration [52]. These two maneuvers increase distal sodium delivery, but they do not increase the excretion of potassium; this action lends support to the hypothesis of a defect in the distal secretory mechanism of potassium as the cause of the decreased excretion of potassium from the post-UUO kidney.

Bilateral ureteral obstruction

Renal blood flow, glomerular filtration rate, and ureteral pressure

The triphasic pattern of RBF and ureteral pressure changes that characterizes UUO is not seen after BUO or unilateral obstruction of a solitary kidney. RBF increases after the first 90 min of BUO, as it does with UUO [56]. However, between 90 min and 7 h of BUO, the RBF is significantly lower than the RBF during the same time interval of UUO (Figure 7.5A). The decrease in RBF is accompanied by an increase in renal vascular resistance during BUO to a greater level than with UUO (Figure 7.5B). However, by 24 h of BUO, the RBF is as low and renal vascular resistance as high as with 24 h of UUO (Figure 7.5A, B). However, ureteral pressure is higher than in UUO (Figure 7.5C). Gulmi *et al.* found eRBF to be markedly decreased even at 48 h of BUO [57]. After release of BUO, the RBF remained significantly decreased in comparison with preobstruction values for 11 h of the study. Jaenike showed that the distribution of RBF after BUO is much different from that in the UUO model [58]. Using radioactive microspheres, he showed that 55% of RBF remains in the cortical nephrons and only 14% is shifted to the innermost renal zones. Yarger *et al*. used micropuncture studies to demonstrate a decrease in both whole kidney as well as single nephron clearance of para-aminohippurate (PAH) (17% and 55%, respectively) [59]. Solez *et al*., using intravenous [^{125}I]-albumin infusion, showed a marked decrease in inner medullary plasma flow to 8% of normal by 18 h of BUO [46].

Ureteral pressure follows a similar pattern for the first 4½ h of both BUO and UUO, i.e. a progressive rise in pressure (Figure 7.5C). However, after 4½ h of BUO, the ureteral pressure remains elevated until 24 h, whereas in UUO, ureteral pressure begins to progressively decline to control levels by 24 h of ureteral occlusion (Figure 7.5C). This increase in ureteral pressure has been documented to at least 48 h after BUO [57]. Dal Canton *et al*. demonstrated an increase in intratubular pressure from 14.1 to 28.9 mmHg ($P < .005$) with micropuncture studies in rats after 24 h of BUO [60]. This change in intratubular pressure caused a decrease in the hydrostatic pressure gradient from 31.7 to 20.0 mmHg and a decrease in the effective filtration pressure at the afferent end of the glomerulus from 16.6 to 5.4 mmHg ($P < .001$). Yarger *et al*. also measured both proximal and distal tubular pressures during micropuncture studies of rats after 24 h of BUO and found the pressures to be 30 and 27.7 mmHg, respectively, in comparison with 9.2 and 6.5 mmHg,

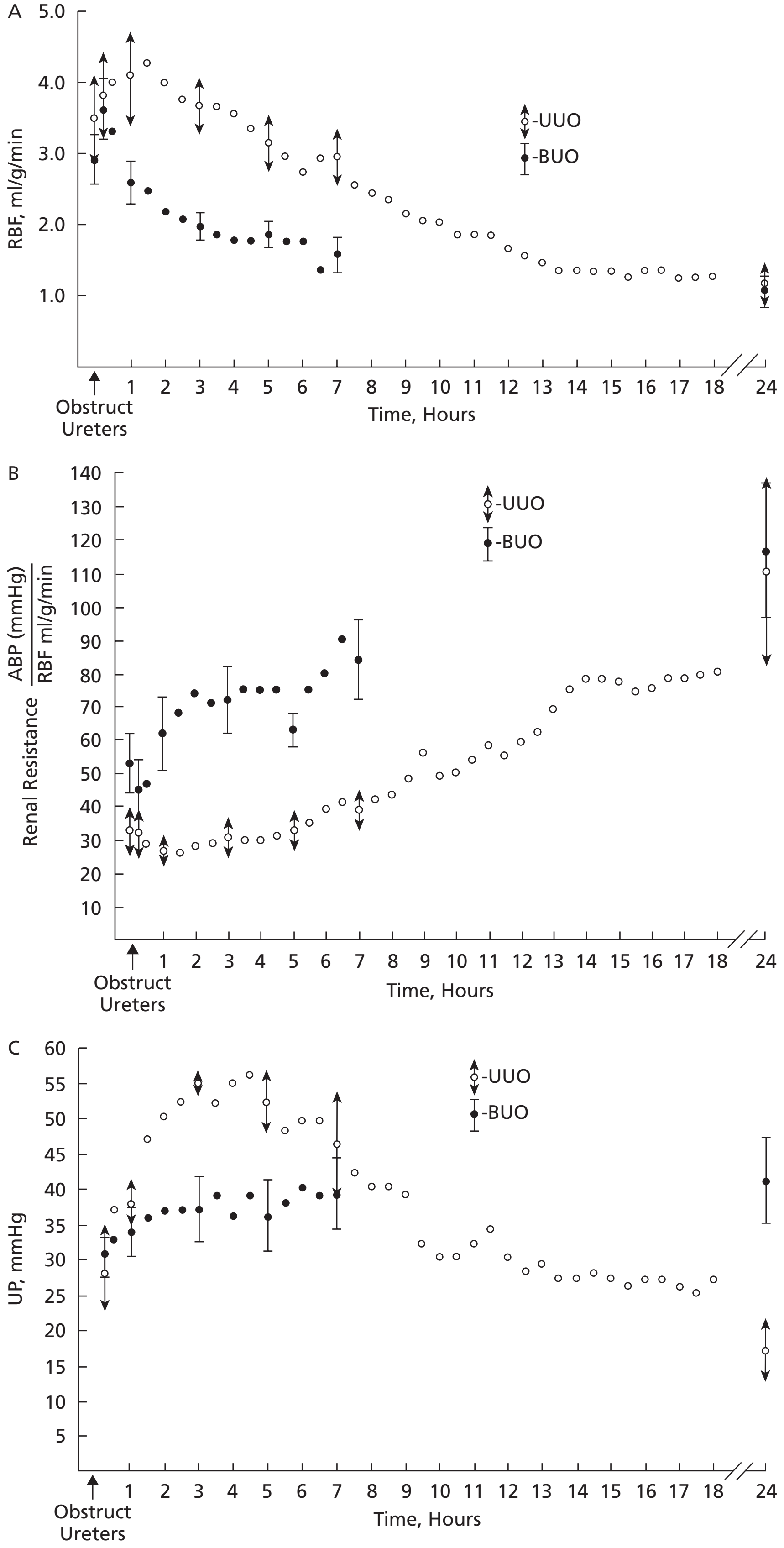

Figure 7.5 Comparison of renal blood flow (RBF) in unilateral ureteral occlusion (UUO) and bilateral ureteral occlusion (BUO), demonstrating a similar pattern of change over the 24-h period, although the RBF in the BUO model is below that of the UUO model from 1½ to 7 h postobstruction.
(B) Comparison of the renal resistance (RR) in UUO and BUO demonstrating similar changes over the 24-h period with the RR in the BUO model being higher than in the UUO model in the early hours, corresponding to the lower RBF at that time in BUO.
(C) Comparison of ureteral pressure (UP) in UUO and BUO demonstrating significant difference in the UP at 24 h postobstruction.

respectively in UUO rats ($P < .001$). The micropuncture studies of both groups have confirmed what other investigators have observed from the monitoring of ureteral pressure, a rise after 24 h of BUO. Therein lies one of the differences between BUO and UUO. BUO passes through a phase of preglomerular vasodilation and then a postglomerular vasoconstriction and remains in this state. This explains the progressive and persistent rise in ureteral pressure despite a decrease in RBF and an increase in renal vascular resistance. In contrast, during UUO, the kidney passes through three phases: preglomerular vasodilation, postglomerular vasoconstriction, and, finally, preglomerular vasoconstriction (see above).

The GFR after 48 h of BUO is significantly decreased (22% of control values) in comparison with preobstruction GFR [57]. This decrease was also seen by Jaenike in rats after 24 h of BUO; the GFR was reduced to 20% of the control value [58]. With micropuncture studies, Jaenike also found single nephron GFR (SNGFR) to be 34% of normal [58]. However, Yarger and Harris showed that the number of functioning nephrons, as well as the GFR of those functioning nephrons, is higher for kidneys after BUO than after UUO [61]. Harris and Yarger also demonstrated that 84% of superficial and 49% of juxtamedullary nephrons filter after 24 h of BUO, as opposed to 40% of superficial and 12% of juxtamedullary nephrons after 24 h of UUO [32].

Dal Canton *et al*. performed micropuncture studies on rats after 24 h of BUO [60]. They observed a decrease in SNGFR after release of BUO to 40% of normal, secondary to an increase in intratubular pressure from 14 to 30 mmHg. There was little change in glomerular capillary pressure (46 and 50 mmHg, pre- and postobstruction, respectively). With relief of obstruction, there was a 52% increase in afferent arteriole resistance, resulting in a low SNGFR in the postrelief period. Therefore, in both BUO and UUO, there is a decline in SNGFR after 24 h of ureteral occlusion. In UUO this is secondary to an increase in afferent arteriolar resistance, whereas in BUO it is secondary to a rise in intratubular pressure with little change in afferent arteriolar resistance (Table 7.3).

Table 7.3 Comparison of the effects of unilateral ureteral (UUO) and bilateral ureteral obstruction (BUO) in glomerular hemodynamics (from Dal Canton *et al*. [60]).

	P_T	P_G	AAPF	R_a	SNGFR
24-h UUO	===	↓	↓↓	↑↑	↓↓
24-h BUO	↑↑	===	===	===	↓↓

AAPF, afferent arteriole plasma flow; P_T, intratubular pressure; P_G, hydrostatic pressure across glomerular capillaries; R_a, resistance of single afferent arteriole; SNGFR, single nephron glomerular filtration rate.

Involvement of atrial natriuretic peptide

Several investigators have postulated the accumulation of a "substance" during BUO that would affect the glomerular hemodynamics in such a way that there would be preglomerular vasodilation and postglomerular vasoconstriction, as seen with late-phase BUO. This substance would not accumulate during UUO, because it could be excreted by the contralateral kidney. Wilson and Honrath demonstrated such a substance with cross-circulation studies in rats [62]. When the cross-circulation was between a donor rat with 24 h of BUO and a normal recipient rat, there was an immediate increase in both sodium and water excretion. This did not occur when the donor rat was subjected to 24 h of UUO (Figure 7.6).

Harris and Yarger also postulated the existence of a circulating diuretic factor that accumulated only during BUO [55]. They observed an increase in urine flow and sodium excretion after relief of BUO, UUO with contralateral nephrectomy, or UUO with the continuous intravenous reinfusion of urine from the contralateral kidney. In contrast, the UUO-alone animals did not have postobstructive diuresis and natriuresis.

The discovery of atrial natriuretic peptide (ANP) paved the way for studies on the role of ANP in BUO. ANP has several physiologic effects, including vascular smooth muscle relaxation, i.e. vasodilation, natriuresis, and diuresis. The natriuretic and diuretic actions of ANP have been shown to be caused by: (1) an increase in GFR through afferent arteriole vasodilation and efferent arteriole vasoconstriction; (2) an increase in glomerular capillary ultrafiltration coefficient (Kf); and (3) inhibition of the glomerular–tubular feedback mechanism [63]. These glomerular hemodynamic effects point to ANP as the circulating diuretic and natriuretic substance postulated by previous investigators to explain the observed changes in RBF, ureteral pressure, and glomerular filtration during BUO.

Fried *et al.* demonstrated an elevated level of plasma ANP in rats after 24 h of BUO , but not after 24 h of UUO (393 vs 261 pg/mL;, $P < .01$) [64]. Purkerson *et al.* have shown plasma ANP levels of 400 pg/mL in rats with 24 h of BUO, in comparison with 71 pg/mL in rats with UUO ($P < .01$) and 81 pg/mL in controls ($P < .01$) [65]. Elevated ANP has also been demonstrated in patients with either BUO or UUO of a solitary kidney, or in volume-replete dogs after 48 h of BUO [57, 66].

With the demonstration of elevated levels of ANP in BUO, it became clear that ANP was likely the factor previously postulated by Wilson and Honrath [62] and Harris and Yarger [55]. The stimulus for the elevated

Image not available in the electronic edition

Figure 7.6 Changes in urine flow (upper panel) and sodium excretion (lower panel) in normal rats undergoing cross-circulation with donor rats having bilateral (O, group A) or unilateral (O, group B) ureteral ligation of 24-h duration. Standard error of mean value is shown; significance of the difference from the mean control value: (reproduced from Wilson and Honrath [62], with permission).

plasma ANP seems to be an increase in intravascular volume, as determined by an elevation in pulmonary capillary wedge pressure (PCWP) and body weight in volume-replete dogs with BUO [57]. In support, clinical studies in patients on chronic hemodialysis show that intravascular volume, and not the degree of renal failure, is the stimulus for an elevation in their plasma ANP levels.

Other mediators

Reyes *et al*. have examined the role of NO in BUO [67]. When N-NAME, an L-arginine antagonist, was infused, there was a further decrease in GFR and eRPF compared to controls, suggesting that NO was maintaining GFR and eRPF during BUO. This was confirmed by showing that there was an improvement in GFR and eRPF, as well as a decrease in renal vascular resistance with the infusion of L-arginine into rats with unilateral release of 24 h of BUO. Other factors may also be involved in BUO. Reyes and Klahr demonstrated that antibodies to either platelet activating factor, endothelin, or vasopressin can ameliorate changes in GFR and eRPF either during or after release of BUO [68–70].

Tubular changes

There are differences between tubular function after release of BUO and UUO (Table 7.4). Several investigators have described marked diuresis and natriuresis after the relief of either BUO or UUO of a solitary kidney in humans [66, 71–74]. Maher *et al*. described a significant increase in urine volume and sodium excretion after relief of obstructive uropathy [72]. The urinary flow more closely followed the osmolar excretion than the sodium excretion in this patient study. The predominant urine solute during this osmotic diuresis was urea, accounting for 37–68% of the total urine osmolality. When serum urea returned to normal, the diuresis ceased. Maher *et al*. therefore postulated that the physiologic diuresis was caused by a high serum urea concentration, which ceased when the BUN returned to normal.

Muldowney *et al*. measured total exchangeable sodium to determine whether the postrelease natriuresis of BUO is pathologic or merely a physiologic elimination of excess body sodium [75]. They found that patients with chronic obstructive uropathy had an increase in total exchangeable body sodium before release of obstruction. After relief of the obstructive uropathy, total exchangeable body sodium levels returned to normal within 2–3 weeks. The loss of sodium in the urine did not result in clinical sodium depletion in any of the patients. Muldowney *et al*. concluded that the increased loss of sodium in the urine upon release of chronic obstructive uropathy is a physiologic reduction of excess body sodium to normal levels.

Gulmi *et al*. described nine patients with obstructive uropathy and postobstructive diuresis and natriuresis [66]. Patients with obstruction had a significantly elevated plasma ANP, in comparison with the control group of patients (Figure 7.7). There was an increase in both absolute and fractional excretion of sodium that subsided with improvement in renal function. This natriuresis and diuresis was associated with an elevation of serum ANP in all patients, which decreased as water and salt excretion decreased (Figure 7.7). Because ANP is a known diuretic and natriuretic, it may be one of the main factors causing the loss of water and salt in the postobstructive state.

In animals, the release of BUO is accompanied by profound diuresis and natriuresis as well. There seems to be a dual mechanism for the increase in water and

Table 7.4 Differences in tubular function after release of unilateral and bilateral ureteral obstruction (24 h).

	Control	Unilateral	Bilateral
Postobstructive diuresis		Absent	Present
Percent of filtration excreted (V/GFR)	1%	Decreased to 0.5%	Increased to 18%
Na^+ excretion fraction filtered			
Proximal tubular reabsorption		Decrease	Decrease
Distal tubular reabsorption			Decrease
Proximal fraction reabsorption	58%	74%	46%
Distal fraction reabsorption	12%		34%
Fraction K^+ excreted	12.3%	Decreased to 7%	Increased to 90%
Concentration U:P	7.6	1.35	1.47

GFR, glomerular filtration rate; P, plasma; U, urine; V, volume.

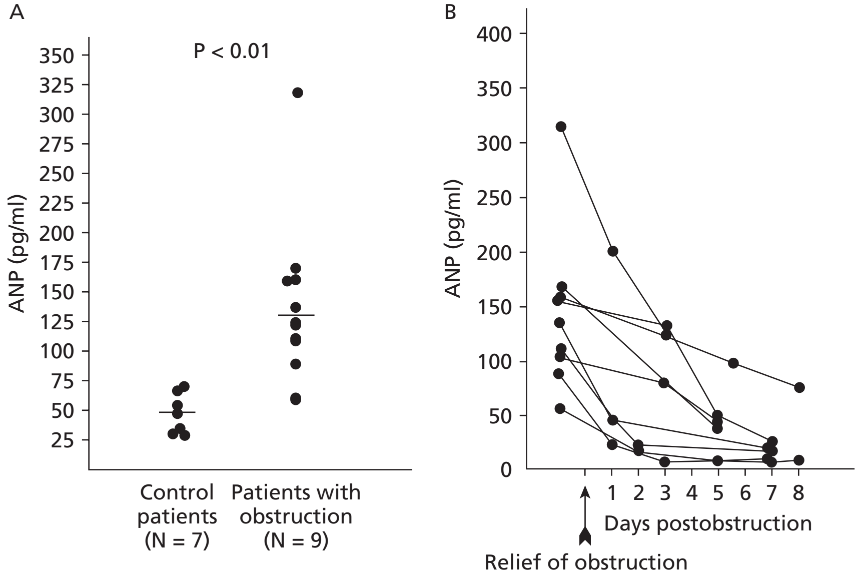

Figure 7.7 Plasma atrial natriuretic peptide levels in (A) control group and patients with obstruction, and (B) before and after relief of obstruction (reproduced from Gulmi *et al.* [66], with permission).

sodium loss after release of BUO. Yarger *et al.* investigated the site of impaired tubular reabsorption of sodium in surface nephrons with micropuncture techniques [59]. They observed impaired fractional sodium reabsorption in the distal tubule, with normal fractional reabsorption of sodium in the proximal tubule. Jaenike confirmed a postobstructive diuresis and natriuresis in rats after the release of BUO [58]. He also demonstrated that exclusion of sodium intake after obstruction did not decrease the postrelief diuresis and natriuresis of BUO. This contradicts the conclusion of Muldowney *et al.* in human studies [75], that postobstructive diuresis and natriuresis are appropriate responses to increased total body sodium accumulated during obstruction. Jaenike infused urea into normal rats and into rats after relief of UUO to achieve levels of urea similar to those observed in rats with BUO [58]. This caused no increase in salt and water excretion. Therefore, the postobstructive natriuresis and diuresis do not seem to be secondary to an increased solute load. Jaenike did demonstrate a defect in sodium transport in the distal tubule and suggested that this defect is a direct mechanical effect of obstruction at the distal tubule.

McDougal and Wright also described an increase in sodium and water excretion that lasted for 24–36 h after relief of 30-h BUO in rats [76]. However, they observed a reduction in sodium and water reabsorption in both the proximal and distal nephrons. They also observed increased permeability in the tubule wall to both mannitol and inulin. Because there is increased permeability of the tubule after 30 h of obstruction, it is likely that sodium and other ions have increased permeability, thus elevating their tubular fluid concentration by increasing sodium backflux into the tubule. However, this permeability defect existed only after BUO and not UUO; therefore, it seemed unlikely that a permeability change should occur only when both kidneys are obstructed. McDougal and Wright suggested the possibility that the accumulation of a substance during BUO is a cause of the permeability defect [76].

Fried *et al*. reported experiments in which animals with UUO were compared with two groups of animals with BUO [64]. One group was given access to water after relief of BUO, and one was not. Elevation of plasma ANP and postobstructive diuresis was found in both groups of rats with BUO, but not in rats with UUO. The two BUO groups lost weight before the relief of BUO, and both groups still demonstrated elevated levels of ANP. Fried *et al.* postulated decreased renal excretion and/or metabolism or enhanced atrial production of ANP to explain the elevated ANP levels during BUO. However, the acute weight loss seen in these animals should not be associated with volume expansion and consequently atrial stretch. Because atrial stretch is the main stimulus for ANP, this does not seem to be the explanation.

Gulmi *et al*. produced BUO in dogs, a larger animal model, allowing the invasive monitoring of PCWP in addition to weight loss or gain during BUO [57]. The BUO animals were subdivided into a volume-replete group given normal saline during the 48 h of obstruction and a second group not given intravenous saline after ureteral occlusion. Before release of obstruction, the volume-replete group demonstrated significantly elevated plasma ANP levels in comparison with preobstruction values. This was not seen in the BUO without saline group (Figure 7.8). The elevation of ANP was accompanied by elevations in both PCWP and weight gain in the volume replete BUO group. The BUO group not given normal saline did not have an elevation in PCWP, nor did the animals gain weight. However, both groups of animals did achieve equivalent decrees of renal failure by 48 h of BUO.

The data strongly suggest that the intravascular volume status during BUO, not the degree of renal failure and consequent inability of the kidney to excrete and/or metabolize ANP, leads to the elevation of ANP via atrial stretch. This has been borne out by clinical studies in chronic renal failure patients on hemodialysis showing that the patient’s intravascular volume status, measured by PCWP and body weight, determined the level of plasma ANP and not the degree of renal failure [77, 78]. Upon relief of obstruction, both groups of BUO animals exhibited diuresis and natriuresis. However, the group with an elevation of ANP demonstrated prolonged excretion of sodium and water, in comparison with the BUO group, without an increase in plasma ANP. Therefore, an elevated plasma ANP may not be required to achieve the diuresis and natriuresis observed after the release of BUO. A direct effect of obstruction on the tubule itself may contribute to the enhanced excretion of sodium and water of BUO, as suggested in previous studies [58, 76, 79].

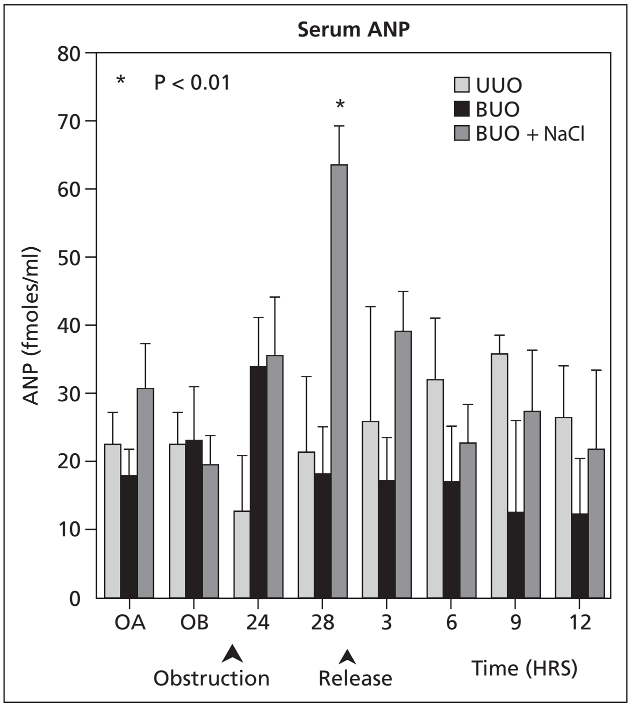

Figure 7.8 Atrial natriuretic peptide (ANP) in all groups both before and after release of 48-h obstruction. OA, preclearance time zero; OB, postclearance time zero (reproduced from Gulmi *et al*. [57], with permission.

There is an enhanced increase in potassium excretion after release of BUO [76, 79]. There is an increase in both the absolute potassium excretion as well as the fractional excretion of potassium [61, 80]. The increase in the delivery of sodium, the tubular fluid flow rate, and plasma potassium are important stimuli for the enhanced excretion of potassium after the release of BUO [40, 61].

There is an impaired ability to acidify the urine and lower the pH in response to an acidemia during BUO. This is believed to be secondary to an inability to secrete hydrogen ions against a gradient. The decrease in the tubular reabsorption of sodium distally may contribute to the inability of the kidney to excrete hydrogen ions.

In the postrelief BUO kidney, the ability to concentrate urine is impaired. There is an increase in free water clearance (C_{H2O}) after release of BUO. This is accompanied by an overall increase in total solute excretion (Cosm) [66, 76]. The major sites affected are the loop of Henle, distal tubule, and collecting duct, mostly from the juxtamedullary nephrons [3]. The mechanisms most often proposed to explain the decrease in concentrating ability in the kidney after obstruction are an inability of the medullary interstitium to maintain its hypertonicity and an insensitivity of the tubule to vasopressin [3]. The inability to establish the medullary tonicity necessary to concentrate urine comes from the inability of the thick ascending limb of the loop of Henle to reabsorb sodium after obstruction [48]. This ultimately decreases the tonicity in the medullary interstitium and, consequently, the reabsorption of water. Hanley and Davidson demonstrated a significant decrease in the response of the cortical collecting tubule to vasopressin [48]. This was also observed in ligated–deligated rats, which showed no changes in either $U_{Na}V$ or $U_{osm}V$ measured before and after the administration of vasopressin [76].

Interestingly, the highest density of ANP receptors in the nephron is found in the inner medullary collecting duct [63]. Several investigators have demonstrated that ANP can inhibit both sodium chloride absorption in the inner medullary collecting duct [81, 82], and vasopressin-stimulated osmotic water permeability in the same segment of the nephron [81]. These factors have previously been invoked to explain the concentrating defect in postobstruction renal function. Therefore, ANP elevated during BUO may be either the primary cause for a concentrating defect in obstructive uropathy or a contributing factor enhancing an already diminished ability of the kidney to concentrate urine in the postobstruction period. This information is summarized in (Figure 7.9).

Studies have shown that changes in aquaporins can be documented in BUO. BUO for 24 h caused a decrease in aquaporin-2 expression in the inner medulla to 26% of control; 48 h after relief of BUO, the reduction in aquaporin expression persisted. Seven days after the release of BUO, renal excretion of water and electrolytes had returned almost to normal. There was only a partial reversal of the decrease in aquaporin-2 at that time, which coincided with a decrease in the urinary concentrating ability (in response to an 18-h period of thirst). Thus, changes in aquaporin-2 may also be involved in the changes in concentrating ability after BUO [83].

Fibrosis in unilateral ureteral obstruction

Gross changes in the human kidney

The appearance of the kidney after ureteral obstruction varies with the presence of an intrarenal versus extrarenal collecting system, with the length and degree of obstruction, and the presence or absence of infection. The presence of the renal parenchyma completely around an intrarenal collecting system limits its ability to dilate. Expansion of an extrarenal collecting system, however, is not limited by the renal parenchyma. Therefore, the intrarenal system, although obstructed to the same degree and duration as the extrarenal system, may not exhibit the same degree of hydronephrosis; however, the degree of renal damage may be worse.

Acute complete ureteral occlusion may cause little change in the collecting system, especially if there is an intrarenal collecting system; it may take several days to develop significant collecting system dilation under these conditions. Chronic obstruction can produce an enlarged, normal, or atrophic kidney, again depending on the length and degree of obstruction, as well as the presence of an intra- or extra-renal collecting system [8]. Usually the collecting system will dilate with time, especially with extrarenal collecting systems, resulting in gradual compression of the renal papilla. Over time, the collecting system will enlarge to the point that the tissue between the calyces will thin, resulting in calyceal enlargement. Ultimately, the calyces will coalesce, with

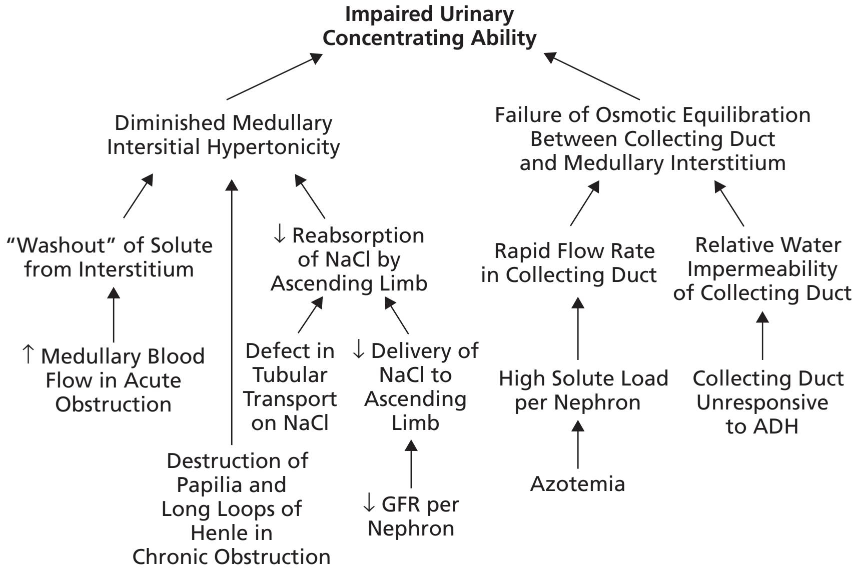
Impaired Urinary Concentrating Ability
Diminished Medullary Intersitial Hypertonicity
Failure of Osmotic Equilibration Between Collecting Duct and Medullary Interstitium
"Washout" of Solute from Interstitium
↓ Reabsorption of NaCl by Ascending Limb
Rapid Flow Rate in Collecting Duct
Relative Water Impermeability of Collecting Duct
↑ Medullary Blood Flow in Acute Obstruction
Defect in Tubular Transport on NaCl
↓ Delivery of NaCl to Ascending Limb
High Solute Load per Nephron
Collecting Duct Unresponsive to ADH
Destruction of Papilia and Long Loops of Henle in Chronic Obstruction
↓ GFR per Nephron
Azotemia

Figure 7.9 Mechanisms by which urinary tract obstruction may impair urinary concentrating capacity of the kidney (reproduced from Walsh *et al.*, Campbell's Textbook of Urology, 8th edition, 2002).

thin septa between them and a "rim" or "shell" of parenchyma remaining peripherally.

Microscopic changes in the kidney: experimental

Initially most of the microscopic changes are confined to the tubules with little effect on the glomeruli [84, 85]. The glomeruli seem relatively resistant to change, except for a slight increase in size and a thickening of Bowman's capsule. The development of hyalinization and connective tissue proliferation are not seen until 231 days of ureteral ligation, and only in relatively few glomeruli [84]. The tubules initially undergo dilation of the lumen with flattening of the epithelium. After approximately 21 days of obstruction, there are barely discernible tubules in several areas of the renal parenchyma on microscopic section.

Fibrosis

Nagle and Bulger used electron microscopy and described the appearance of collagen fibers in the kidney by 7 days after UUO, with an increase up to 32 days [86]. At 32 days, diffuse interstitial collagen was found in the cortex and outer medulla. Sharma *et al.* studied the immunohistochemical localization of collagen subtypes and used *in situ* hybridization to localize collagen mRNA in rabbits with 16 days of UUO [87]. In these studies, interstitial volume was increased, as well as interstitial collagen III and IV, and fibronectin. Increases in collagen I were only in focal, peritubular accumulations.

Collagen is visualized by blue staining in trichrome-stained slides. Specific collagen subtypes have been localized immunohistochemically in rats studied from 1 to 28 days after UUO. Increases in cortical and medullary interstitial space were found; these changes were significant by 7 days after UUO. Collagen III was increased by 3 days in both the cortex and medulla, and medullary collagen was further increased by 7 days after UUO. Prominent changes in collagen I were detected at 14 days after UUO. Collagen IV, laminin, and fibronectin also showed prominent changes by 3 days; these components continued to increase through 14 days. Glomerular fibrosis was not prominent, with only small changes in collagen I being found after 14–21 days of UUO [88].

Despite the relative sparing of the glomerulus from fibrosis, there is a clear decline in glomerular filtration in the obstructed kidney. This is consistent with the finding in a variety of chronic renal diseases, that the presence of interstitial fibrosis is a major determinant of GFR [89–91]. There are several possible reasons for this finding. Tubular atrophy can result in atubular glomeruli; these glomeruli, which are detached from their corresponding proximal tubules, are unable to filter properly [92]. The accumulation of extracellular matrix can isolate tubules from their oxygen supply and may also result in obliteration of peritubular capillaries, which can also result in decreased GFR [93–95].

Central to the fibrotic process is the fibroblast, or its activated form, the myofibroblast. It has long been known that there is an increase in fibroblasts in the obstructed kidney [86, 96, 97]. The transformation of fibroblasts to myofibroblasts [identified by α-smooth muscle actin (SMA) expression] was demonstrated as early as 1973 in a classic paper by Nagle *et al*. [98]. The source of the fibroblasts and myofibroblasts has been the subject of intense research over the last 15 years. Much evidence has been presented that epithelial–mesenchymal transdifferentiation, the process by which renal tubular epithelial cells become (myo)fibroblasts, is a major factor in the development of fibrosis [99]. This will be discussed below. However, not all the recent literature supports this claim. The resolution of these differences will be important in targeting future therapies.

As of this time, there are at least six different cell types which have been implicated in the increase in fibroblasts and/or myofibroblasts in UUO [100] (Figure 7.10). The cell types include: (1) local fibroblasts; (2) tubular epithelial cells; (3) endothelial cells; (4) bone marrow cells; (5) renal progenitor cells; and (6) pericytes/perivascular fibroblasts.

Local fibroblasts

Despite the fact that there are resident fibroblasts in the kidney, their contribution to fibrosis was largely unstudied. Picard *et al*. used immunofluorescence and electron microscopy to examine this issue [101]. They found an increase in α-SMA in resident fibroblasts as early as 1 day after UUO. Furthermore, they showed a decrease in 5′-nucleotidase, a marker of fibroblasts., with progression of UUO. This demonstrates activation of resident fibroblasts to myofibroblasts in UUO.

Tubular epithelial cells

In the epithelial–mesenchymal transition (EMT), epithelial cells undergo transdifferentiation to fibroblasts or myofibroblasts. *In vitro*, it has been shown that tubules can be transformed into cells with a myofibroblastic phenotype. Many studies have demonstrated that incubation of renal tubular epithelial cells with varying doses of the profibrotic cytokine transforming growth actor-β (TGF-β) causes the following changes [102, 103]:

- The typical cobblestone appearance of cells in culture is replaced by the elongated spindle shape associated with fibroblasts.
- Using scanning electron microscopy, the cells are shown to lose their apical–basal polarity and cell surface

microvilli. The apical–basal polarity is replaced by a front end-back end-fibroblast-like polarity with cytoplasmic projections at the front end.

- Under transmission electron microscopy, large bundles of actin microfilaments and dense bodies are seen.
- The presence of α-SMA in the TGF-β-transformed cells was confirmed. α-SMA is used as one of the defining markers of EMT, demonstrating the presence of an activated fibroblast or myofibroblast. However, other investigators have used fibroblast specific protein-1 (FSP-1) as a marker for EMT [104]. FSP-1, also known as S100-A4, has been used to demonstrate the presence of fibroblasts in UUO. However, questions about the specificity of FSP-1 remain, and may confound some of the findings in UUO.
- EMT is accompanied by loss of the epithelial antigen, E-cadherin. The effects of TGF-β are blocked by a neutralizing antibody to TGF-β. The loss of cell adhesion, expression of the mesenchymal markers, and subsequent degradation of the basement membrane allows for changes in shape and motility, which lead to migration into the interstitial space (Figure 7.11).

Several studies have examined EMT in UUO. Yang and Liu showed a marked decrease in E-cadherin and a marked increase in α- SMA in UUO [105]. There was also an increase in TGF-β receptors in renal tubules. When hepatocyte growth factor was administered, interstitial fibrosis was decreased, as well as the expression of α-SMA. Iwano *et al*. used a combination of bone marrow chimeras and transgenic reporter mice, and studied the expression of FSP+ cells in UUO [106]. They determined that a small population of FSP+ cells derived from bone marrow, but a larger proportion arose from local EMT of proximal tubular cells. Both FSP+ cell populations were able to synthesize collagen and to proliferate. Sato *et al*. have also demonstrated decreased E-cadherin and increased α-SMA expression in UUO [107]. Using Smad-3 knockouts (a downstream effector of TGF-β), they demonstrated that the decrease in E-cadherin and the increase in α-SMA can be reversed. Furthermore, Smad-3 knockouts exhibit less fibrosis

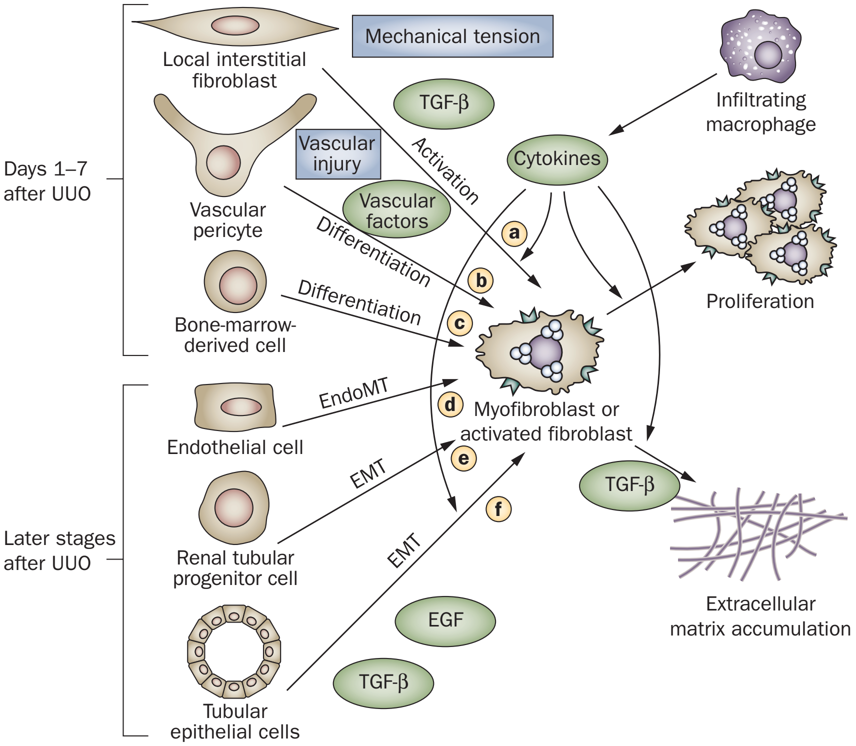
Mechanical tension
Local interstitial fibroblast
TGF-β
Infiltrating macrophage
Cytokines
Vascular injury
Activation
Days 1–7 after UUO
Vascular pericyte
Vascular factors
Differentiation
a
b
Proliferation
Differentiation
c
Bone-marrow-derived cell
EndoMT
d
Myofibroblast or activated fibroblast
Endothelial cell
EMT
e
TGF-β
f
Later stages after UUO
Renal tubular progenitor cell
EMT
Extracellular matrix accumulation
EGF
TGF-β
Tubular epithelial cells

Figure 7.10 Origins of activated fibroblasts and myofibroblasts in the obstructed kidney. Local resident fibroblasts (a) are activated by mechanical stretch or cytokines such as transforming growth factor (TGF)-β. Myofibroblasts derive from differentiation of (b) vascular pericytes (as a result of vascular injury and release of vasoactive factors), (c) bone marrow derived cells, (d) endothelial cells [via endothelial–mesenchymal transition (EndoMT)], (e) renal tubular progenitor cells, and (f) tubular epithelial cells [via epithelial–mesenchymal transition (EMT), which is induced by various cytokines]. Myofibroblasts and activated fibroblasts proliferate and produce extracellular matrix. Infiltrating macrophages release cytokines that contribute to many of these processes. EGT, epidermal growth factor; UUO, unilateral ureteral obstruction (reproduced from Grande and Lopez-Novoa [100], with permission).

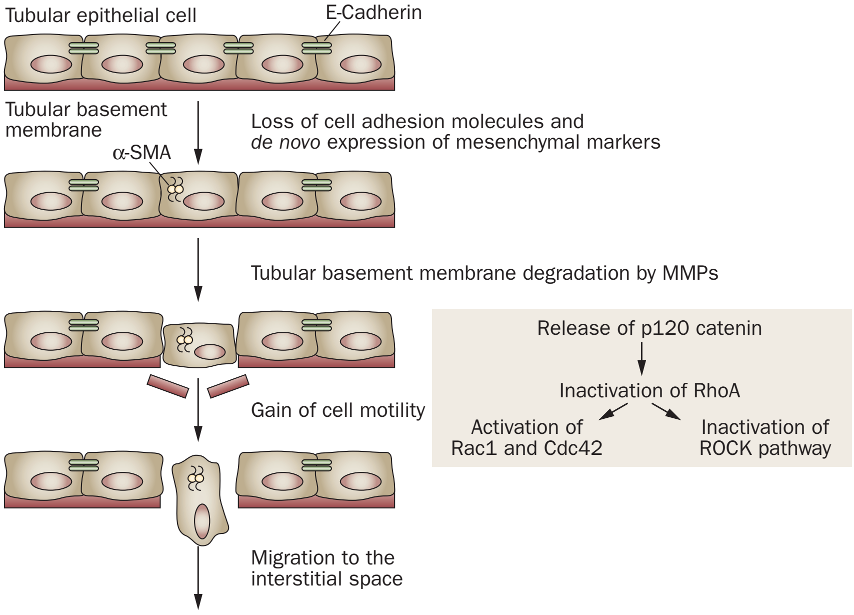
Tubular epithelial cell
E-Cadherin
Tubular basement membrane
α-SMA
Loss of cell adhesion molecules and *de novo* expression of mesenchymal markers
Tubular basement membrane degradation by MMPs
Release of p120 catenin
Inactivation of RhoA
Activation of Rac1 and Cdc42
Inactivation of ROCK pathway
Gain of cell motility
Migration to the interstitial space

Figure 7.11 Stages of epithelial–mesenchymal transition (EMT). The initial steps of EMT – loss of cell adhesion (owing to downregulation of E-cadherin) and *de novo* expression of mesenchymal markers such as α-smooth muscle actin (SMA) – are followed by degradation of tubular basement membrane by selective matrix metalloproteinases (MMPs); finally, acquisition of motility (as a result of activation of small Rho GTPases) allows the cell to migrate from the tubular to the interstitial space. ROCK, Rho-associated coiled-coil forming protein kinase (reproduced from Grande and Lopez-Novoa [100], with permission).

than their wild-type counterparts. To examine the specific role of FSP-expressing fibroblasts in the fibrosis of UUO, Iwano *et al*. used methods to selectively remove the FSP+ cell population in the kidney. When these mice underwent UUO and kidneys were harvested 10 days later, both type I collagen deposition and fibrosis were reduced. This suggests that FSP+ fibroblasts are at least partially responsible for the fibrosis of UUO [106].

Endothelial cells

A new source of fibroblasts has recently been identified in cardiac fibrosis. Zeisberg *et al.* demonstrated that, similar to epithelial cells, TGF-β could induce endothelial cells to undergo transition to fibroblasts [108]. Treatment of mice in a model of pressure overload-induced fibrosis with BMP-7 reduced both endothelial cell transition to fibroblasts and the resulting cardiac fibrosis. Similarly in UUO, the same group found that 30–50% of fibroblasts coexpressed the endothelial cell marker CD-31. In addition, using transgenic mice and lineage tracing with TIE-2, the endothelial origin of a subset of fibroblasts in UUO was confirmed [109].

Bone marrow cells

Two different studies have demonstrated that bone marrow cells contribute to the population of fibroblasts in UUO. In the first, Iwano *et al*. demonstrated that a small number of bone marrow-derived cells are FSP+, but, as discussed above, a much larger number were derived from tubular epithelial cells [106]. In a more recent study, Roufosse *et al*. used transgenic mice in which production of collagen was accompanied by expression of luciferase reporter gene [110]. They clearly demonstrated fibrosis in the UUO model, but in chimeric mice in which bone marrow cells were labeled, no increase in reporter gene could be detected. Their conclusion was that intrinsic renal cells are responsible for collagen synthesis in UUO.

Renal progenitor cells

Cells identified as renal progenitor cells have been identified through BrdU staining. It has been shown that the BrdU-positive cells are among a population of cells which express vimentin, heat shock protein-47, and α-SMA [111]. The contribution of this population to fibrosis is unknown.

Pericytes

A population of pericytes has been shown to be the source of myofibroblasts in fibrosis in UUO. Pericytes are cells that line the vasculature; the smallest capillaries are partially covered by individual pericytes, whereas

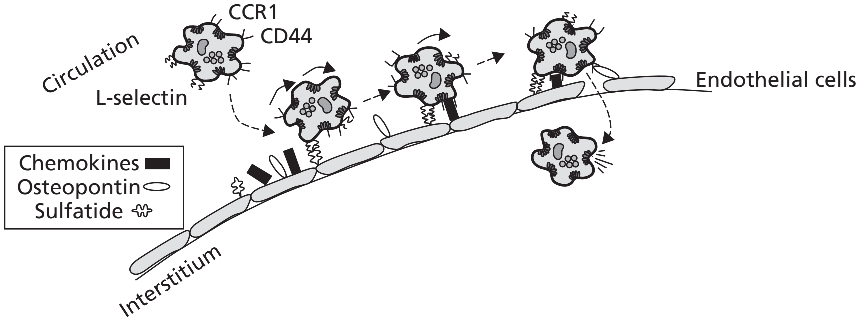

Figure 7.12 Hypothetic representation of cellular infiltration in unilateral ureteral obstruction (UUO) based on data obtained with knockout mice. UUO induces macrophage infiltration in the tubulointerstitium. In UUO, the interaction between L-selectin and sulfatide seems to mediate the initial contact (rolling) between macrophages and the vascular endothelium. These rolling macrophages are exposed to adhesion molecules like chemokines and osteopontin expressed on endothelial cells. The chemokines bind to chemokine receptors (in UUO mainly the CCR1) on the macrophages. Osteopontin binds to the CD44 receptor. This results in firm adhesion and transendothelial migration of macrophages. The role of other important molecules [including intercellular adhesion molecule-1 (ICAM-1), vascular cell adhesion molecule-1 (VCAM-1), and monocyte chemoattractant protein-1 (MCP-1)] involved in cellular infiltration shown to be induced in UUO has not been studied yet and should give a more complete picture of cellular infiltration in UUO (reproduced from Bascands and Schanstra [120], with permission).

intermediate size vessels are lined with cells whose properties are between pericytes and typical vascular smooth muscle cells [112]. Pericytes themselves have a phenotype which is between vascular smooth muscle cells and fibroblasts. Duffield *et al*. have published two studies in which they demonstrate that pericytes are the primary source of collagen-producing cells in UUO. In the first, transgenic mice in which green fluorescent protein (GFP) expression is under the regulation of the collagen 1α1 promoter, pericytes showed increased expression of GFP, indicating that collagen 1α1 was induced [113]. Furthermore, the pericytes detached and moved away from the capillaries. There is no unique marker for pericytes; however, both α-SMA and NG2 (high molecular weight melanoma associated antigen) have been used. In kidney, there was a marked increase in both NG2 and α-SMA in GFP-positive cells after UUO. In the more recent study, elegant fate-mapping studies were used to investigate the source of myofibroblasts in UUO [114]. The investigators demonstrated that *in vitro*, epithelial cells transform into myofibroblasts in the presence of TGF-β. However, the same cells labeled *in vivo*, either with red fluorescent protein or β-galactosidase, neither migrated past the tubular basement membrane nor contributed to the *in vivo* population of myofibroblasts.

Macrophage infiltration

There are very few macrophages in the normal kidney. Macrophages have also been localized in the obstructed kidney by morphologic examination [96]. Needleman *et al*. demonstrated that macrophages contributed to the exaggerated eicosanoid release in the isolated perfused rabbit kidney [115, 116]. Use of monoclonal antibodies has led to immunohistochemical identification of macrophages. Diamond *et al*. described an increase in macrophages in interstitial tissue by 12 h after UUO [117]. There was a continued increase through 96 h. Others have confirmed the presence of interstitial macrophages in UUO [88, 118, 119]. In a recent article by Bascands and Schanstra [120], the contribution of various adhesion molecules to the transendothelial migration of macrophages has been reviewed (Figure 7.12). Use of mice with knockout of specific adhesion molecules demonstrated that L-selectin and sulfatide mediate the initial contact between circulating macrophages and the underlying vascular endothelium. The CCR1 receptor on macrophages is a site for binding adhesion molecules like osteopontin, which can then effect adhesion of macrophages to the endothelium. Furthermore, using either CCR1 or osteopontin knockout mice, researchers have been able to demonstrate decreased fibrosis in the UUO model [121, 122].

TGF-β

Macrophages, fibroblasts, and tubular cells in the obstructed kidney produce a wide variety of cytokines which contribute to the fibrosis of obstruction. Foremost among these mediators is TGF-β, whose role in EMT was described above. Increased mRNA expression of TGF-β was found as early as 10 h after obstruction and was increased through 96 h [117, 123]. When tubules and glomeruli from the obstructed kidney were separated, glomerular TGF-β mRNA was found not to differ from controls, whereas tubular TGF-β mRNA was increased in UUO [124]. TGF-β localization in obstructed kidneys has been studied using immunohistochemistry, and conflicting results have been found. Wright *et al.* found that tubular TGF-β was increased in the obstructed rat kidney medulla; cortical TGF-β was not greatly affected by UUO [88]. This was confirmed by the measurement of tissue levels of TGF-β, which were found to be increased in the medulla after UUO. TGF-β has been found in association with interstitial macrophages in early obstruction and not in association with tubules [117]. TGF-β has also been found in interstitial cells, which have not been characterized, but may be either macrophages or fibroblasts. Kaneto *et al.* examined renal samples from nine patients who underwent nephroureterectomy because of transitional carcinoma of the ureter [125]. All patients exhibited hydronephrosis by either ultrasound or IVU. Control renal tissue was obtained from presumed normal sections of kidneys of patients with renal tumors. Compared to control tissue, kidneys from patients with hydronephrosis exhibited increased interstitial volume and collagen deposition. Immunoreactive TGF-β was detected in the interstitium, but not in the tubules, and was increased in obstructed kidneys.

Strategies to decrease fibrosis

Over the last 25 years, investigators have attempted to decrease the fibrosis of UUO through either drug treatments or genetic manipulation. Many of these have targeted either TGF-β or angiotensin II, both of which have been found to be profibrotic in UUO (for reviews see [1, 2]). In studies in our laboratories, rats underwent UUO and were given either control monoclonal antibody, 1D11 or enalapril (Angiotensin converting enzyme inhibitor), or 1D11/enalapril combination, for 14 days. Kidneys were harvested and examined for fibrosis and FSP-1 expression, apoptosis, macrophage infiltration, and TGF-ß expression. UUO was found to induce fibrosis, apoptosis, macrophage infiltration, and TGF-ß expression in the obstructed kidney. Administration of either 1D11 or enalapril individually significantly decreased all these changes; when 1D11 and enalapril were combined, there was little additive effect, and the combination did not provide full protection against damage [126]. The results demonstrate that, for the most part, combination therapy is not additive in UUO. This could be due the continued presence of a physical obstruction or to biochemical differences between UUO and other renal disease models. Furthermore, it suggests that other targets may be amenable to pharmacologic manipulation in UUO.

Proliferation and apoptosis

Recovery from tissue injury involves both proliferation and apoptosis of resident and infiltrating cell populations. With coordination of these processes, the tissue can recover. When apoptosis and/or proliferation are dysregulated, tissue fibrosis ensues. Truong *et al.* provided the first detailed analysis of both apoptosis and proliferation in UUO [127]. They studied the tubular, interstitial, and macrophage components from 0 to 90 days of UUO. There was virtually no change in glomerular apoptosis or proliferation throughout the period examined. Tubular proliferation peaked at day 10, whereas interstitial proliferation exhibited two peaks: a broad peak at days 10–20, and a sharper peak at day 75. The rate of proliferation of tubule cells was 10-fold higher than that of interstitial cells. There was a sharp peak in tubular apoptosis at day 25, whereas interstitial apoptosis peaked at day 75. The apoptotic rate was twofold higher in tubular cells than in interstitial cells. Choi *et al.* demonstrated similar findings in mice studied from 4 to 45 days of UUO [128]. Tubular apoptosis was maximal at day 15, whereas interstitial apoptosis was still increasing at day 45.

Chevalier *et al.* examined apoptosis and proliferation in adult rats with 3-day UUO [1]. There was an increase in apoptosis and proliferation in both tubular and interstitial compartments, which was not affected by blockade of either the AT1 or AT2 receptor. Miyajima *et al*. studied apoptosis and proliferation in iNOS knockout mice [129]. They showed that iNOS knockout mice exhibited more tubular apoptosis and more proliferation than wild-type controls. In contrast, when rats were treated with 1D11, a TGF-β antibody, tubular apoptosis was markedly decreased, whereas tubular proliferation was increased [130]. Chevalier *et al.* also studied expression of bcl-2 and bax, antiapoptotic and proapoptotic proteins, respectively [131]. Sham-operated kidney showed diffuse tubular bcl-2 and bax staining. In 14-day UUO, bcl-2 was increased in scattered nonapoptotic tubules, with minimal staining in apoptotic dilated tubules. Bax staining overlaps bcl-2. In contrast, Miyajima *et al*. found virtually no expression of bcl-2 in sham-operated or obstructed kidneys [130]. However, in the presence of 1D11, and markedly decreased levels of renal TGF-β, there was expression of bcl-2 in obstructed kidneys.

Docherty *et al.* suggest that tubular apoptosis is a major contributor to fibrosis in UUO, and conversely that inhibiting apoptosis decreases fibrosis in UUO [132]. Thus, they review the evidence that tubular apoptosis in UUO can result from several factor associated with the response to UUO, including stretch, hypoxia, and oxidative stress. The apoptosis caused by these factors then produces an inflammatory response, resulting in the synthesis and deposition of extracellular matrix (Figure 7.13. Thus, the function of several known antifibrotic agents can be explained by effects on apoptosis. We have recently used a tetrapeptide antioxidant,

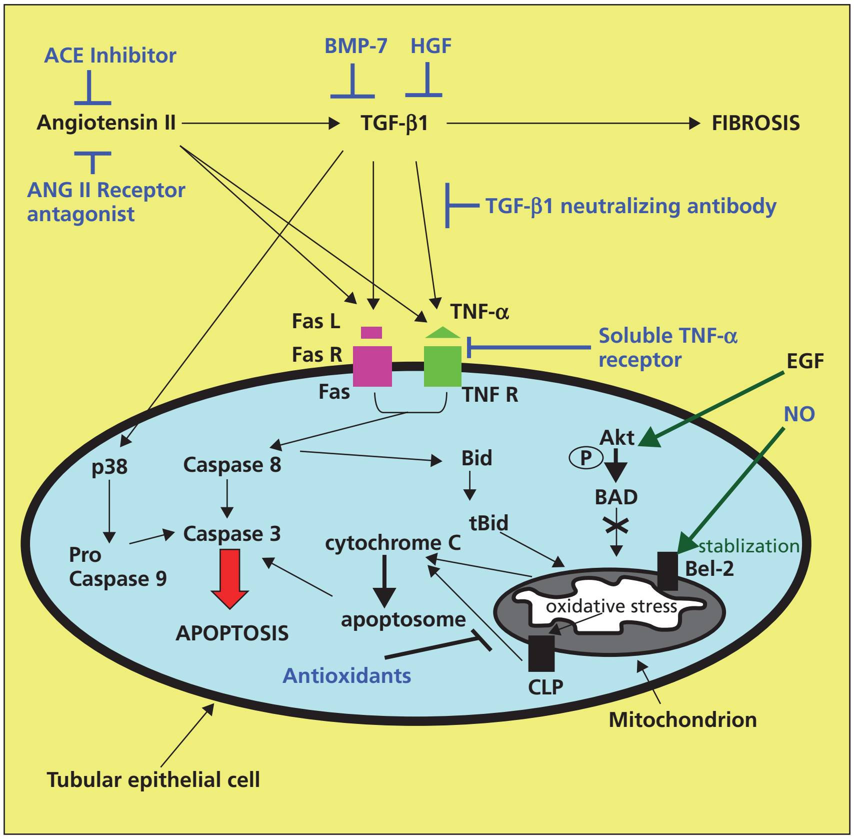
ACE Inhibitor
BMP-7
HGF
Angiotensin II
TGF-β1
FIBROSIS
ANG II Receptor antagonist
TGF-β1 neutralizing antibody
Fas L
Fas R
TNF-α
Soluble TNF-α receptor
EGF
Fas
TNF R
NO
Akt
P
p38
Caspase 8
Bid
BAD
tBid
Pro Caspase 9
Caspase 3
cytochrome C
stablization
Bcl-2
oxidative stress
APOPTOSIS
apoptosome
Antioxidants
CLP
Mitochondrion
Tubular epithelial cell

Figure 7.13 Summary of mediators and mechanisms shown to block tubular cell apoptosis following unilateral ureteral obstruction (UUO). Figure details the likely mechanisms of action of antiapoptotic strategies utilized in the inhibition of tubular cell apoptosis in animal models of UUO. Blunt ended blue lines and green arrow-tipped lines indicate the site/stage of antiapoptotic effect. CLP, cardiolipin; NO, nitric oxide; BMP-7, bone morphogenic protein-7, TGF, transforming growth factor; TNF, tumor necrosis factor; EGF, epidermal growth factor; ACE, angiotensin converting enzyme; HGF, hepatocyte growth factor; ANG, angiotensin (reproduced from Docherty *et al*. [132], with permission).

which concentrates in the inner mitochondrial membrane to prevent cellular apoptosis, in the UUO model. We were able to demonstrate decreased apoptosis and fibrosis, along with decreased oxidative stress in the UUO kidney [133]. Most of the strategies which target tubular apoptosis also have effects on epithelial–mesenchymal transdifferentiation, and it may be difficult to separate these two different pathways. With the new description of other cell types and other cell transdifferentiations, as well as mediators such as cytokines or reactive oxygen species, there may be new targets which can be developed to improve antifibrotic therapy.

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CHAPTER 8

Special Anesthetic Considerations for Endourology: Ureteroscopy and Percutaneous Nephrolithotomy

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Endourology presents unique challenges for providing anesthesia that allows for safe care, optimum surgical conditions, and a low side effect profile. Patients with nephrolithiasis frequently present with comorbidities linked to the "metabolic syndrome" (hypertension, elevated body mass index, diabetes or insulin resistance) that should be considered carefully when planning an anesthetic [1]. Further, spinal cord injury patients have a higher incidence of nephrolithiasis, due to chronic infections, immobility, and metabolic conditions, as do other chronically immobile patients. These patients pose specific challenges to providing safe anesthesia. The faster recovery afforded by minimally invasive techniques, compared to conventional open techniques, opens a wider patient population to candidacy, such as those with severe cardiac or pulmonary comorbidities who might not have been considered for conventional approaches.

Many types of anesthesia have been used successfully for ureteroscopic and percutaneous techniques for renal stone extraction, including general, subarachnoid block (spinal), epidural, and sedation with local anesthetic supplementation [2–4]. This chapter will address procedure-specific risks and requirements, physiologic changes from intraoperative surgical and anesthetic stresses, the assessment of patient-specific risks, and postoperative recovery from the anesthetic. All of these issues should influence the choice and planning of the anesthetic for an individual patient. Lastly, the strengths and preferences of the surgeons and anesthesiologists will influence anesthetic technique. Communication between these parties and the patient should occur prior to the day of surgery in order to choose an optimal anesthetic technique.

Procedural considerations for endourology

Fluid absorption during endourologic procedures can be significant during transurethral resection of the prostate (TURP), but is less of an issue during more minor ureteroscopic procedures. A study quantitating fluid absorption in 23 patients undergoing ureteroscopy (either semi-rigid or flexible scopes), using normal saline irrigation at a maximum infusion pressure of 200 mmHg, demonstrated mean fluid absorption of 54 mL (maximum 137 mL). In this study, the mean total irrigation used was 2531 mL (maximum 5580 mL) [5]. Moreover, another study looking at the amount of fluid absorbed during percutaneous nephrolithotomy in 148 patients, where all patients received 0.9% saline as irrigant, revealed maximum absorption of 474 mL. Factors suggested to increase irrigant absorption included use of a primary percutaneous access tract, elevated blood loss, high amounts of irrigating fluid, and significant perforation of the pelvicalaceal wall. This study failed to demonstrate any intra- or post-operative electrolyte imbalances [6]. Furthermore, during procedures involving continuous bladder irrigation, urine output is often difficult for the anesthesiologist to quantitate. This aspect emphasizes the importance of communication between surgeon and anesthesiologist, in that the surgeon may be able to estimate urine output while visualizing the surgical field.

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Both percutaneous nephrolithotomy (PCNL) and ureteroscopy involve irrigation fluids at room temperature, which removes heat from the patient. This, in combination with the known redistributive effect of general anesthesia (GA), which alters patient heat distribution, potentiates the risk of hypothermia. The redistribution of heat from the patient's core to the periphery, and subsequent heat loss to radiation, conduction, convection, and evaporation put the patient at risk. GA interferes with the body's ability to maintain its thermal set-point through hypothalamic dysfunction. Even mild hypothermia is known to contribute to an increase in perioperative cardiac ischemic events (by threefold), surgical wound infections (by threefold), decreased metabolism of drugs, increased bleeding and transfusion requirement, and increased length of stay [7]. Diligent attention to patient warming during and after induction of anesthesia, through forced air warming, maintenance of the room temperature, warming intravenous fluids and blood products, is essential to avoid hypothermia. This is especially true when large irrigation volumes are to be administered.

Patients with urinary infections or evolving urosepsis associated with obstructing ureteral stones may be febrile, relatively hypovolemic, and hyperdynamic, requiring careful anesthetic management. Fever increases metabolic rate, fluid requirements, and rate of metabolism of certain drugs. This presents complications with anesthetic management that will be covered below.

Lastly, renal stones positioned higher in the ureter, upper kidney poles, and staghorn calculi all increase the complexity of maneuvers required for removal, possibly increasing the duration of surgery and depth of anesthesia required. Similarly, position and size of ureteral tumors approached endoscopically may dictate length of procedure and depth of anesthetic required.

Ureteroscopy: procedural risks and anesthetic consideration

Fortunately, since modern ureteroscopy does not invade the peritoneum and avoids major blood or fluid loss requiring significant volume resuscitation, as well as serious hemodynamic challenges from catecholamine release, the procedure itself poses a low risk of cardiac complications. (<1%) [8]. As a lower abdominal procedure, without significant inherent postoperative pain or pulmonary dysfunction, individual patient risk factors take greater importance, and will be the focus of a later section of this chapter.

Many types of anesthesia for ureteroscopy have been described; from GA to regional and local, either with or without sedation, and all have been used successfully. Many surgeons advocate the use of GA with muscle relaxation (including endotracheal intubation) for most ureteroscopic stone manipulations. This preference reflects concern about safely accessing the kidney and ureters during spontaneous respiration or other voluntary or involuntary patient movement [9]. GA facilitates a quiescent surgical field as ventilation can be briefly held, to permit focus of the YAG (yttrium–aluminum–garnet) laser on the stone, minimizing risk of inadvertent injury to the urethra, bladder, and pelvic vessels. Lastly, in patients undergoing semi-rigid ureteroscopy, a GA provides better analgesia to facilitate better patient tolerance of a larger ureteroscope.

Muscle relaxation may be more important when accessing mid-to-upper urethral stones than lower. Even when the stone is in the lower ureter, it may migrate higher during manipulation with irrigation pressure and instrumentation. This circumstance makes a higher level of anesthesia and neuromuscular blockade (NMB) desirable, to avoid the possibility of ureteral tears or avulsion, or other retroperitoneal injury. However, multiple studies have demonstrated the safety and efficacy of both local anesthesia and spinal anesthesia for ureteroscopic procedures [2, 10, 11]. If rigid equipment of larger caliber is needed, then more substantial intraoperative analgesia and anesthesia will be required. If using more modern, small diameter flexible scopes, local anesthesia and sedation may be more successfully employed and tolerated. In a recent review of the literature, it was noted that in select [American Society of Anesthesiologists (ASA) physical status I and II] patients, the incidence of ureteral trauma is minimal whether utilizing GA, subarachnoid block, or local with monitored anesthesia care (MAC) for the procedure [2, 12–14].

Other factors which may influence the depth of anesthesia and analgesia necessary are patient gender and complexity of the planned procedure (larger, more complex stone burden, location, or more complex tumor for resection). Patients in whom a procedure of long duration is expected may tolerate GA or regional anesthesia better. Women tend to tolerate local anesthesia somewhat better than men, perhaps due to better tolerance of instruments through the shorter membranous urethra and bladder neck [10]. The use of higher distending pressures within the ureter also predicts higher discomfort levels and makes toleration of lighter anesthesia more difficult. Several factors that may dictate ureteroscopic treatment of renal calculi rather than extracorporeal shock-wave lithotripsy (ESWL) or PCNL, e.g. super morbid obesity, acute infection, and coagulation abnormalities, also complicate provision of safe anesthesia. These factors must also be considered carefully when planning the anesthetic [9].

Lastly, positioning the patient for ureteroscopy deserves brief mention. Fortunately, the usual lithotomy position with the patient's head near the anesthesia team makes airway management and maintenance of anesthesia straightforward. The lithotomy position increases venous return from the lower extremities, which is well-tolerated by most patients. Warner *et al*. found that the overall duration of lithotomy, greater than 2 h in 991 patients while under GA, increased the risk of lower extremity sensory neuropathies significantly, compared to procedures of shorter duration [15]. This emphasizes the need for shorter duration of procedures and optimal hemodynamic management during these procedures.

Percutaneous nephrolithotomy: patient risks and anesthetic considerations

The risks associated with this procedure are more significant due to the increased invasiveness, prone positioning, surgical stress response elicited, and potential blood loss relative to ureteroscopic procedures. However, PCNL has been performed safely and with low morbidity in many patients, including those of ASA III or IV, as well as the morbidly obese [16]. The procedure is considered "intermediate" in cardiac risk [1–5 % incidence of cardiac death or myocardial infarction (MI)] according to the 2007 American College of Cardiology (ACC)/ American Heart Association (AHA) Guidelines (Table 8.1), due to the risks associated with the procedure itself.

As with ureteroscopy, all types of anesthesia have been used successfully for PCNL procedures. This includes general, neuraxial, and local with sedation during access, tract dilation, and stone manipulation in the same setting. This is well-described in the literature [3, 4, 17]. In our institution, GA is most frequently used due to the anticipated duration and complexity of the procedure, as well as surgeon preference. Patient positioning, complexity of procedure, and patient comorbidities are all factors to be considered when planning the anesthetic for PCNL. Interestingly, one randomized controlled trial demonstrated improved patient satisfaction, shorter postanesthesia care unit (PACU) times, and less postoperative pain through postoperative day 2, in 180 patients undergoing PCNL via combined spinal–epidural anesthesia versus GA [3].

With regards to positioning, the prone oblique position is more frequently utilized for PCNL. However, the supine oblique position has also been employed to facilitate access to the surgical site [18]. Prone positioning increases the complexity of the anesthetic somewhat. Airway maintenance, adequate ventilation, and avoidance of cervical spine and pressure point injuries require more proactive maneuvers, especially in the obese and morbidly obese. Bagrodia *et al.* confirmed that obesity had no impact on cost, length of stay, and complication and stone-free rates compared to normal weight patients [19].

Table 8.1 Cardiac risk* stratification for noncardiac surgical procedures (reproduced from *Circulation* 2007;116:1971–1996, ©2007 American Heart Association, Inc., with permission).

Text not available in the electronic edition

*Combined incidence of cardiac death and nonfatal myocardial infarction.
†These procedures do not generally require further preoperative cardiac testing.

Airway maintenance:

Prone positioning requires that the patient's face be maintained free of pressure on prominences (eyes, nose, ears, cheekbones), with appropriate cushioning and support. Several commercial foam face cushions and support systems are available. The cervical spine must be maintained in a neutral position. The endotracheal tube must be taped securely at an appropriate depth and positioned free of kinks or pressure so that there is not obstruction within the airway during patient repositioning or during the procedure. A bite block should be placed between upper and lower molars (or gums if patient is edentulous) to prevent patient biting on the tongue, soft tissues, or endotracheal tube. The trachea must be positioned without pressure or risk of impeding a patent airway. One useful commercial device that serves all these purposes is the ProneView® Protective Helmet system (Dupaco, UK). This device is used for head and face positioning and incorporates a padded cradle, supported by short posts, with a mirror underneath to allow easy visualization of the patient's face and endotracheal tube (Figure 8.1).

Positioning

During the time in which the patient is turned prone and positioned for surgery, the anesthesia team must remain hypervigilant about the patient's physiologic and anesthetic status. Monitoring devices may be removed tem-

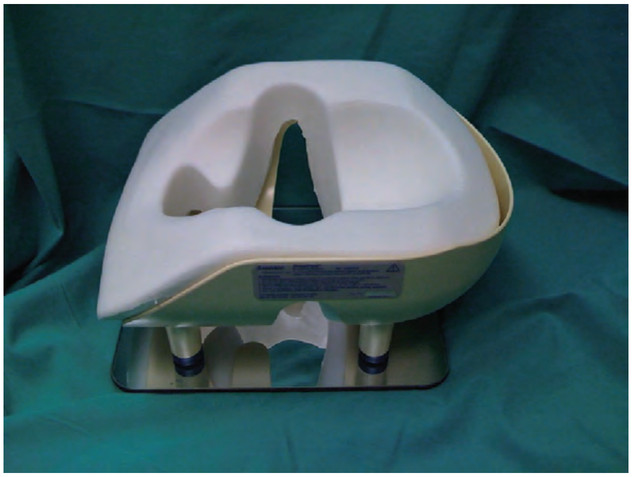

Figure 8.1 ProneView® protective helmet system (Dupaco, UK).

porarily while turning to avoid entanglement. These monitors must be quickly replaced, however, to monitor changes that can occur during repositioning. With such changes in position, the ability to ventilate the patient's lungs, maintain intravascular volume distribution (changes in venous return), cardiac output, as well as adequate anesthesia levels relative to variable levels of stimulation, can present quite a challenge. For a healthy, adequately anesthetized patient, these may be clinically inconsequential; however, for those with marginal cardiovascular or pulmonary reserve, it can be a more dangerous time. The anesthesia team must ensure the airway is maintained while repositioning, without dislodging the endotracheal tube, and maintain cervical spine neutrality. Although cervical spine injury during prone positioning under anesthesia is rare, it has been reported with both overflexion and overextension during prolonged procedures [20]. At greatest risk are patients with known or presumed cervical spine pathology, including Down's syndrome or rheumatoid arthritis, or patients with myelopathic symptoms. Furthermore, protruding facial features must be positioned and maintained free of compression (ears, nose, lips), and the eyes and orbital contents especially must avoid direct pressure damage. This, fortunately, appears to be rarely reported in the literature but remains a concern. Lastly, postoperative visual loss (POVL) is a dreaded yet infrequent complication of prone spine surgery (0.2% of spinal surgeries in one review [21]). However, prone positioning itself has not been identified as an independent risk factor for POVL [20].

The chest must be elevated on rolls to protect intra-abdominal contents from pressure, and to facilitate positive pressure ventilation by allowing full diaphragmatic excursion and full lung expansion. Elevated intra-abdominal pressure may impede effective mechanical ventilation and oxygenation if this does not occur. Improper positioning of chest rolls and lower extremities may result in hemodynamic changes from compression of the inferior vena cava and iliac veins, thereby decreasing preload and cardiac output.

The shoulders should be supported without significant forward rotation so as to protect both the brachial plexus from excessive shear force and optimize perfusion to the upper extremities. Breasts in women and external genitalia in men must be checked such that they are free of compression. Arms can be tucked and padded at the sides, or, more frequently, as with our institution, raised above the head with both shoulders and elbows positioned at 90°. Of course, this presumes that the patient has no restrictions to range of motion or risk of shoulder dislocation. Such positioning allows access to the arms in case further peripheral intravenous access is needed intraoperatively. The patient's knees and feet should be protected with padding and slightly flexed such that there is little or no contact with the operative bed. Fortunately, there is as yet no convincing evidence in the literature that the incidence of peripheral nerve injury is increased during prone positioning [20].

If the procedure can be performed under local anesthesia with sedation, positioning can be achieved with the patient's assistance prior to heavy sedation, to ensure comfort and adequate padding. If it is performed under epidural or spinal anesthesia with a local anesthetic that induces a motor block, the patient may need to be moved by the surgical team, but will be able to position the head and upper body, prior to sedation being initiated. Further, some neuraxial blocks may allow delayed onset of the motor block, which gives the patient time for lower body positioning.

Access to the middle and lower poles of the kidneys is usually achieved subcostally. But occasionally access to the upper calyx is necessary to reach the ureteropelvic junction, proximal ureter, or to improve exposure to calyx and renal pelvis through a supracostal approach. The supracostal approach to the upper pole of the kidney can encroach upon the pleura, so the anesthesiologist and surgeon should communicate frequently during access and tract dilation to monitor for pleural injury, such as hydro- or pneumo-thorax [22]. If supracostal access is necessary, lateral access (at the lateral end of the 12th or 11th rib) during the end-exhalation phase of the respiratory cycle may minimize the chance of pleural and pulmonary injury [22]. Although most surgeons and anesthesiologists prefer GA to control ventilation partly for this reason, safe, successful spinal anesthesia for PCNL (including for supracostal access) has been described [23].

Physiologic changes during prone positioning

A number of physiologic changes to anesthetized patients occur in the prone position. Of benefit is the more uniform distribution of pulmonary blood flow, improving ventilation to perfusion matching and oxygenation [20, 24]. Also, functional residual capacity increases (compared to the anesthetized supine position) in normal weight and less so in obese patients [20]. Care must be taken to position chest rolls so that abdominal contents and the chest wall can move freely, or mechanical obstruction to ventilation may occur, increasing peak airway pressures and inhibiting effective mechanical ventilation. Direct pressure to the abdominal contents may also be injurious, causing decreases in visceral perfusion. Such mechanical compression has been reported to cause ischemia.

Patient mean arterial pressure (MAP) often decreases in the prone position. This has been thought to be due to decreases in cardiac index (CI) and stroke volume [20, 25]. Though the complete reasons for this are unclear, main theories are that this position impedes venous return and/or impedes left ventricular outflow during systole as a result of increased intrathoracic pressure. In either case, the decrease in CI is usually well-tolerated in healthy individuals with good cardiac reserve, due to reflexive increases in systemic vascular resistance and MAP. However, in those with poor cardiovascular reserve, vasopressor support may be indicated to maintain perfusion pressure. Augmentation of preload must be undertaken carefully in those who may be at risk of volume overload (with congestive heart failure, diastolic dysfunction, or renal failure). The decrease in CI underscores the importance of careful positioning to ensure minimal effect on venous return, leaving the abdominal contents and thorax freely mobile.

Complexity of surgical procedure: considerations for the anesthetic

With a larger more complicated stone burden that requires a prolonged surgical time, the likelihood of needing general or neuraxial (spinal or epidural) anesthesia increases. For cases involving access, dilation, and stone extraction during the same procedure, a "type and screen" for blood products should be considered in the event of unanticipated significant blood loss. Further, adequate intravenous access should be secured prior to initiation of surgery. Utilizing the "type and cross" method of reserving blood products can lead to extra cost, blood wastage, and transfusing red cells of increased age that have diminished oxygen carrying capacity. The time for most blood banks to convert a "type and screen" to available crossed units is minimal unless the patient has been recently transfused or has rare antibodies. Many centers have described a "maximum surgical blood ordering schedule" to minimize these issues [26].

Longer PCNL procedures may lead to significant dependent edema to inferiorly located anatomy. Swelling of the face and laryngeal structures are of greatest concern. These areas should be evaluated carefully prior to extubation. If there is concern regarding supraglottic airway edema, extubation should be delayed until the edema has resolved significantly. This may be evaluated by an endotracheal tube "leak check" to ensure sufficient ventilation exchange around the endotracheal tube with cuff deflated. In most patients, a brief period of head elevation during recovery is sufficient to resolve facial edema and permit extubation.

Preoperative assessment for ureteroscopy and percutaneous nephrolithotomy

The preoperative assessment of patients prior to ureteroscopy and PCNL is similar to that prior to most surgical procedures, except for these lower-risk procedures there is minimal blood loss, fluid loss, or hemodynamic shifts. The fundamental purpose of preoperative evaluation is to obtain pertinent information regarding the patient's current and past medical history (*diagnosis*), to evaluate the patient's intraoperative risk (*risk assessment*), and to consider interventions to minimize patient risk (*optimization*) [27, 28]. The overriding goal is to reduce patient morbidity and risk related to the invasiveness of surgery and the patient's coexisting diseases while promoting perioperative efficiency and reducing length of stay (*perioperative planning*) [27]. The Joint Commission requires that all surgical patients receive a preoperative anesthetic evaluation, and the ASA has established basic standards of preanesthetic care with the goals of assessing and modifying patient comorbidities to improve outcome [27]. The preoperative evaluation is an opportunity to educate and prepare the patient physiologically and psychologically for the upcoming procedure. While it is helpful to have data and risk stratification comments from referring and consulting physicians, notes that state "cleared for surgery" are of little use or benefit to the anesthesiologist preparing for intraoperative management [8, 29].

Inherent to the preoperative assessment is a detailed history and targeted physical examination to identify physiologic changes associated with certain disease states. Evaluating the demographics of age, height, weight, and vital signs, to a full list of medications, allergies, and prior medical, surgical, and social factors is necessary. Review of prior anesthetic records is essential to detect the presence of a difficult airway, latex or drug allergy, history of malignant hyperthermia, autonomic hyperreflexia following spinal cord injury, and the individual's response to surgical stress and specific anesthetics. Furthermore, knowledge of previous laboratory values and ancillary studies facilitates anesthetic planning. If prior labs are unavailable, goal-directed, diagnosis based testing may be appropriate to further elucidate the severity of certain disease states [30–33]. Diagnosis-based preoperative testing may identify a need for change in the patient's perioperative management [32, 34, 35]. Conversely, widespread preoperative testing without consideration of actual utility, cost, or effect on management is not beneficial ("screening" tests), and may actually increase physician liability [31]. Testing should be based upon positive physical examination findings and anticipated physiologic disturbances, such as irrigant absorption or blood loss. Results should aid in assessing the degree of medical optimization and in anesthetic planning.

The preanesthetic medical history should include a complete list of medications, including over the counter and homeopathic herbal agents, in order to define an appropriate preoperative medication regimen and anticipate potential interactions with anesthetic agents. Evaluating the patient's medications and making recommendations prior to surgery serves to minimize potential drug interactions, complications, and cancellations on the day of surgery. Instructions given to the patient both the day before and on the morning of surgery depend upon the patient's comorbidities and the rationale for treatment [36–40]. Examples of some commonly withheld medications prior to surgery are listed in Tables 8.2 and 8.3.

The medication list can also provide clues as to the severity of the patient's underlying disease states. For example, a patient with significant congestive heart failure may be taking diuretics, digoxin, angiotensin II inhibitors [angiotensin II blockers (ARBs) or angiotensin converting enzyme (ACE) inhibitors], beta-blockers, and/or calcium channel blockers. Changes in this regimen could significantly alter the patient's fluid balance, myocardial function, and tolerance of both induction and maintenance of anesthesia. Patients with intracoronary stents, either drug-eluting or bare metal, are typically taking a combination of antiplatelet agents (clopidogrel, ticlopidine, and/or Aspirin) that if discontinued prematurely increase the risk of acute stent thrombosis and MI [38]. These medications should be carefully adjusted in accordance with the ACC/AHA guidelines for management to avoid life threatening acute coronary syndrome and sudden death [36]. Furthermore, certain medications, including most antihypertensives, beta-blockers, H_2 blockers, and proton pump inhibitors should be continued through the morning of surgery. Clonidine, an alpha-agonist, should be continued through surgery to avoid extreme rebound hypertension. Exceptions to the continuation of antihypertensive agents may include ARBs and ACE inhibitors, as they potentiate hypotension common during induction of anesthesia [41, 42]. Continuing beta-blocking agents, statins, and Aspirin for patients with known coronary artery disease or prior MI is paramount for myocardial protection during the perioperative period [36, 39, 40]. This combination of agents has been suggested to maintain balanced coronary blood flow during times of stress and hemodynamic instability [28, 43]. The pleiomorphic (arterial plaque stabilizing) effects of statins may provide this myocardial protection [39, 44].

Table 8.2 Medications commonly discontinued several days prior to surgery.

Medication	Special considerations/comments
Tricyclic antidepressants	Continue for severe depression
Monoamine oxidase inhibitors (MAOIs)	Continue for severe condition (use MAOI – safe anesthetic agents, avoid meperidine)
Metformin	Hold 48 h prior to surgery; risk of lactic acidosis
Oral hypoglycemic agents	Hold the morning of surgery
Herbal therapy (fish oil, ginseng, ginkgo biloba, etc.)	Potential multisystem (anticoagulant, cardiovascular effects)
Warfarin (Comadin)	Stop 3–5 days prior to surgery; if high risk of thromboembolism, bridge with heparin or low molecular weight heparin (LMWH)
Clopidogrel (Plavix), cilostazol (Pletal), dipyridamole (persantine)	Hold for 5–7 days unless antiplatelet, antithrombotic therapy required for secondary prophylaxis (and low risk of surgical bleeding)
	Duration of effect: cilostazol and dipyridamole < clopidogrel, Aspirin, ticlidopine
Nonsteroidal anti-inflammatory drugs (NSAIDs)	Hold for renal insufficiency

None of these recommendations is absolute; decisions made on an individual basis.

Table 8.3 Medications commonly withheld on the morning of surgery.

Medication	Special consideration/comments
Angiotensin converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARBs)	Continue with severe congestive heart failure (CHF), valvular insufficiency, refractory hypertension; otherwise hold to avoid severe hypotension during induction
Diuretics	Continue for severe CHF (esp. if twice daily dosing)
Phospohdiesterase-5 inhibitors	Hold to avoid severe hypotension (except in cases of severe pulmonary hypertension)
Lithium	Interactions with anesthetic agents
Disulfiram (Antabuse)	Affects metabolism of warfarin, phenytoin, etc.
Alendronate sodium (Fosamax)	Transient esophageal irritation
Particulate antacids	Risks pneumonitis with aspiration
Long acting insulin (e.g. NPH, glargine)	Continue the evening before surgery; glargine (Lantus) continue as usual the day of surgery, check glucose morning of surgery
Oral hypoglycemics	Hold the day of surgery
Pyridostigmine (e.g. in myasthenia gravis)	May interfere with neuromuscular blocking agents; continue as usual if risk of severe weakness or dysphasia (craniobulbar symptoms),
Prednisone, chronic immunosuppressive agents	Continue post transplant antirejection regimen, continue antiretroviral agents (HIV)
Low molecular weight heparin (Enoxaparin)	May replace with warfarin; typically hold for 12–24 h depending upon anticipated neuraxial blockade (see Table 8.7, ASRA Guidelines)

Patients with diabetes mellitus pose challenges with the timing of surgical procedures and maintenance of euglycemia. Ideally, insulin dependent diabetics should be scheduled early on the morning of surgery and maintained on exogenous insulin serving basal requirements (glargine, subcutaneous insulin pumps, etc.). Noninsulin dependent diabetics can withhold most medications on the day of surgery. In general, when planning preoperative medication adjustments, careful consideration must be given to both the invasiveness of the anticipated procedure and the surgical stress response, as well as the patient's degree of medical management, functional status, and tolerance of potential hemodynamic shifts [45, 46].

Additionally, certain disease states are of great significance when planning anesthetic management. These need to be identified as the patient's perioperative course and anesthetic management could be significantly altered by derangements in either medical management or physical symptoms. Known predictors of increased perioperative cardiovascular risk include unstable coronary syndromes, recent MI (<30 days), unstable angina, and poorly compensated congestive heart failure [8, 37]. Patients with significant arrhythmias (high-grade atrioventricular block, symptomatic arrhythmias with underlying heart disease, or supraventricular arrhythmias with uncontrolled ventricular rate and severe valvular disease) have increased risk of complications during noncardiac procedures (>5%). Patients presenting with these clinical predictors of cardiovascular disease warrant further evaluation prior to elective procedures, including low-risk procedures. This may involve reviewing an electrocardiogram (ECG), transthoracic echocardiography, or cardiac catheterization to determine ventricular function by a cardiologist to determine myocardial reserve. Intermediate risk factors, such as mild angina pectoris, prior MI (>30 days) by history or pathologic Q waves, compensated congestive heart failure, diabetes mellitus, and renal insufficiency, pose challenges for management but fewer risks to the patient in the immediate perioperative period, especially during lower risk procedures. These issues may be stable and medically managed and may not warrant further evaluation [8].

Assessing pulmonary function requires a basic physical examination and screening assessment that includes questions regarding the history of tobacco use dyspnea, cough, wheezing, stridor, snoring, sleep apnea, or symptoms of recent upper respiratory tract infection [47]. Physical examination should assess diminished breath sounds, wheezing, stridor, or rales, as well as respiratory rate, chest excursion, and use of accessory muscles of respiration. The degree of baseline dyspnea should be assessed relative to physical exertion or exercise tolerance. Further tests (spirometry, lung volumes, and/or arterial blood gas) may be useful to anticipate challenges with anesthesia [48, 49]. Patients with diminished pulmonary reserve from longstanding obstructive or restrictive lung disease, neurodegenerative disorders, or paralysis may not tolerate the muscle relaxation associated with GA, sedation, or neuraxial blockade (spinal or epidural). Such patients may be dependent upon accessory muscles of respiration to maintain adequate ventilation and thus may be prone to needing prolonged intubation and ventilatory support [49, 50].

All of these medical issues must be weighed relative to the risk of surgical procedure, surgical stress response, and potential for hemodynamic fluctuations. Because ureteroscopy and PCNL are considered relatively low risk procedures, even moderate to intermediate patient risk factors pose less overall risk of postoperative morbidity [51]. Such is the case for minor cardiovascular risk factors, including advanced age, abnormal ECG (left ventricular hypertrophy, left bundle branch block, ST-T abnormalities), low functional capacity, history of stroke, or systemic hypertension [8]. It is worth noting that *functional capacity or exercise tolerance* is another important determinant of patient status that translates to perioperative risk [8]. This unique indicator provides valuable information regarding the patient's overall health status and physical robustness. An excellent exercise tolerance [>8–10 metabolic equivalents of task (METS)], even in patients with stable angina, suggests that the patient can generate a cardiac output adequate to meet metabolic demands during surgery. Conversely, patients who experience severe dyspnea or chest pain during minimal exertion (<1–3 METS) may have extensive coronary artery disease and greater risk. Self-reported estimate of exercise tolerance in metabolic equivalents or perceived level of daily exertion has been shown to correlate with perioperative complications [52]. Reilly *et al*. evaluated the predictive value of self-reported exercise tolerance for serious postoperative complications. They demonstrated that limits in preoperative functional capacity, as defined by an inability to walk four blocks or climb two flights of stairs, independently predicted complications with an odds ratio of 1.94 [53]. This study and others further support the lack of benefit of further testing if a patient reports good exercise tolerance, independent of surgical severity, complexity, or anticipated method of anesthesia [53].

With the information detailed in the preoperative assessment, the anesthesiologist planning the anesthetic for the procedure should be adequately prepared to design an anesthetic that minimizes postoperative risks inherent to specific disease states.

Physiologic changes from anesthetics

Surgeons should be aware of the basic physiologic effects of the anesthetics given during endourologic procedures.

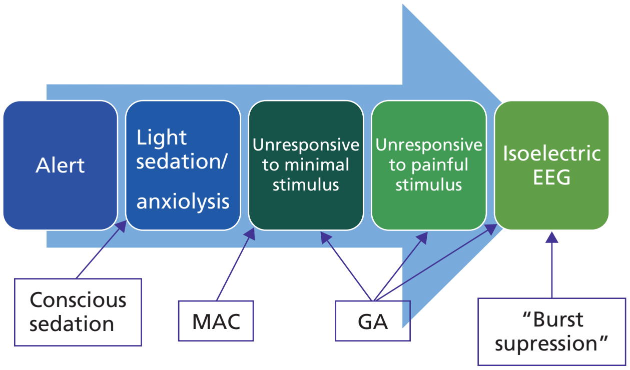
Alert
Light sedation/ anxiolysis
Unresponsive to minimal stimulus
Unresponsive to painful stimulus
Isoelectric EEG
Conscious sedation
MAC
GA
"Burst supression"

Figure 8.2 Spectrum of anesthesia. GA, general anesthesia; MAC, monitored anesthesia care; EEG, electroencephalogram.

Sedation

This technique encompasses a spectrum from light anxiolysis to heavy sedation in which the patient must be aroused to respond (Figure 8.2). If the patient has become unresponsive to pain and other arousal, due to sedative effects, then the anesthetic is defined as "general." Usually a combination of benzodiazepines, opioids, and other intravenous sedative hypnotics, such as propofol or alpha-2 agonists, may be used. Varying degrees of respiratory suppression and cardiovascular depression (mild at sedative doses) can occur, depending on the agents and combinations used.

When determining patient "tolerance" of sedation, it must be considered whether the patient has known or suspected obstructive sleep apnea that may be exacerbated during sedation (especially among the morbidly obese). The hypoventilation that occurs with progressive sedation leads to hypercarbia, which is well-tolerated by most patients, but can be life-threatening for patients with severe pulmonary hypertension due to the pulmonary vasoconstriction and right heart failure it precipitates. Patients with sickle cell anemia also tolerate hypercapnia and hypoxemia poorly due to the propensity of hemoglobin S to further decrease oxygen-carrying capacity under such conditions. With decreasing oxygen levels and the resultant increase in arterial carbon dioxide tension, intracranial pressure could increase to dangerous levels, especially if there is pre-existing intracranial pathology. If any of these conditions are present, airway management with controlled ventilation must be considered (Figure 8.3).

General anesthesia

There are a myriad of physiologic changes that occur under GA. These depend upon the specific anesthetic agents and technique used, as well as the physiology of a specific patient and the details of the procedure. This section will highlight *general* changes of highest impact by system (Table 8.4).

GA means that a patient is rendered unconscious and unresponsive to stimuli. Airway management and ventilatory support that are required vary depending upon the patient and surgical site (Figure 8.3). Muscle relaxation may or may not be a component of GA. If NMB is not required, e.g. as with retrieval of lower ureteral stones or simple ureteral stent placement, then airway management may utilize the native airway, with oxygen supplementation, and total intravenous anesthesia (TIVA). Alternatively, the airway may be managed with the insertion of a laryngeal mask airway device, which is a cuffed mask that sits above the glottic opening in the posterior hypopharynx, with a tube conduit exiting the oropharynx. Several manufacturers make these devices that connect to the anesthesia breathing circuit to allow delivery of oxygen and anesthetic vapors, either during spontaneous or assisted hand ventilation modes. This device lowers the risk of injury to the larynx or trachea from endotracheal tube placement, and also allows for a lighter anesthetic, due to lack of tracheal or carinal stimulation. Unfortunately, the device does not reliably protect against aspiration of gastric contents, as there is no cuffed tube sealing the upper trachea from the oropharynx, and therefore is not appropriate for patients at elevated risk for aspiration. This includes patients who have not fasted for 6 or more hours (solids), patients with gastroparesis and delayed gastric emptying, or those who have recently vomited. Although these laryngeal mask devices can be used with neuromuscular blocking drugs, this technique requires positive pressure ventilation through a partially unprotected airway, possibly increasing the likelihood of aspiration as well as loss of ventilatory pressure and volume from the breathing circuit. Few anesthesiologists choose this technique; however, some will use a low positive pressure assist ventilatory technique to achieve higher tidal volumes than with unassisted, anesthetized, spontaneous ventilation. Many anesthesiologists, though, prefer to have patients spontaneously ventilate through a laryngeal mask device, which poses risks in that this technique increases the possibility of atelectasis under GA if inadequate tidal volumes and minute ventilation occur.

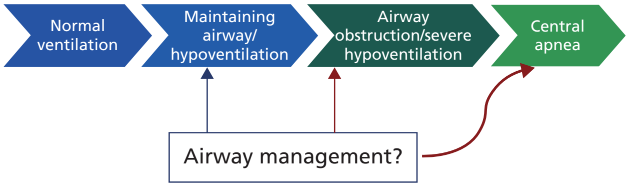
Normal ventilation
Maintaining airway/ hypoventilation
Airway obstruction/severe hypoventilation
Central apnea
Airway management?

Figure 8.3 Effects of anesthetics on breathing.

If NMB is employed during GA, the airway must be managed with endotracheal intubation such that the patient is mechanically ventilated. An endotracheal tube allows for positive pressure ventilation with higher airway pressures than manageable with a laryngeal mask device. It is a definitive airway for prone and lateral positioning and is unlikely to be dislodged if secured in place. This technique also provides better protection against pulmonary aspiration, provided reversal of NMB is timed well with emergence from GA.

Table 8.4 Effects of general anesthesia.

Respiratory	Decrease in functional residual capacity
	Increased atelectasis and V/Q mismatch with possible hypoxemia
	Decrease in minute ventilation (due to drug effects) – offset with controlled mechanical ventilation
	Decrease in airway resistance (with most volatile anesthetics, though tracheal ventilation may counteract this)
Cardiovascular	Decrease in systemic vascular resistance in response to inhaled and most IV agents
	Decrease in venous return
	Decrease in blood pressure due to the above
	Decrease in stroke volume (usually following increased heart rate)
Renal	Decrease in renal blood flow (primarily due to decreased cardiac output and systemic vascular resistance), glomerular filtration rate, and urine output
Neurohormonal	Increased activity of sympathetic nervous system
	Increase in stress hormone release – catecholamines, cortisol, vasopressin, aldosterone, renin–angiotensin
	Blunted autonomic nervous system function in response to insult
Thermoregulation	Most frequently loss of heat to radiation, conduction, evaporation, and convection, with redistribution of blood flow to periphery
	Lowered threshold of hypothalamus for triggering heat conserving measures (shivering and vasoconstriction)

Neuroaxial anesthesia (spinal and epidural)

Both these techniques can induce significant changes in a patient's cardiovascular physiology, and to some degree respiratory physiology, and should not be considered benign or always less "risky" than GA. A meta-analysis of older data demonstrated a decrease in all-cause mortality by 30% in patients receiving neuroaxial blockade as opposed to GA in orthopedic, urologic, general, and vascular surgical procedures. This study also showed a decrease in risk of venous thromboembolism, MI, bleeding complications, pneumonia, respiratory depression, and renal failure as well, although the methods and age of this study limit its widespread applicability [54]. Nonetheless, many practitioners prefer to avoid intubation and/or GA when possible in patients with significant pulmonary comorbidities, even for lower risk procedures, in attempts to avoid atelectasis and airway irritation, and increased risk of postoperative pulmonary complications (PPCs). The American College of Physicians' guideline on reducing PPCs in noncardiac surgery identifies patients undergoing GA as higher risk for PPCs [55], and recommends evaluation for other concomitant risk factors. The guidelines also recommend that these patients receive pre- and post-operative interventions to reduce pulmonary complications, such as triple cough exercises, incentive spirometry, and early ambulation postoperatively.

A spinal anesthetic, or subarachnoid block (SAB), involves the introduction of a small dose of local anesthetic (lidocaine, bupivicaine, or others) with occasional adjuvants, such as opioids, epinephrine, or clonidine, into the subarachnoid space and cerebrospinal fluid at the level of the *cauda equina* (lumbar interspaces L3–4 or L4–5) with a longer, small gauge needle (22–27G). Local anesthetic and adjuvants are chosen based on expected duration of the procedure, postoperative disposition of the patient (to home vs inpatient), and anticipated dermatomal level of surgical stimulation. Baricity and dose of the local anesthetic injected also influence the extent and duration of anesthesia. Spinal anesthesia typically has a quick onset and high rate of success, with a time frame usually of 1–4 h of surgical anesthesia. Unless an adjuvant long-acting opioid is injected, e.g. morphine (which should not be used in outpatients due to the potential for late respiratory depression), SAB does not provide significant postoperative analgesia. With this, another parenteral analgesic may be needed to provide a sufficient "bridge" of analgesia until the patient is ready to take oral analgesics.

Epidural anesthesia involves injection of larger volumes and doses of local anesthetics as well as adjuvants into the epidural space which lies just outside the dural sac. Such larger volumes are needed to ensure significant spread of the local anesthetic within the dural area to reach nerve roots. Frequently, a small catheter is left in the epidural space for redosing. One drawback of epidural anesthesia for endourologic procedures involving the perineum is occasional "sacral sparing" that may occur. This is a deficit of anesthesia in the sacral dermatomes due to the larger size of the L5, S1, and S2 nerve roots [56]. A uniform block is dependent on spread of the local anesthetic (LA) and other drugs around multiple nerve roots, and fibrous and venous tissue in the dural space. If there is postsurgical or other scarring within this space, the spread of local anesthetic and subsequent analgesia can be hindered, resulting in a slower onset of action relative to SAB. This may be advantageous in that a smaller band of anesthesia may be achieved, if desired, by using smaller doses of local anesthetics. Similar to spinal anesthesia, the addition of opioids and other adjuvants, i.e. alpha-2-agonists, epinephrine and clonidine, to the local anesthetic may increase the "density" or effectiveness of the block, as well as increase the duration. Choice of specific local anesthetic and its dose affect the duration and density of the block, as well as the extent of motor block achieved. Level of placement of the catheter, age of patient, and patient position during initiation of the block also affect block spread and duration. Larger volumes and doses make LA toxicity a more likely complication with epidural anesthesia, though this is rare when incremental dosing is achieved and after a negative "test dose" of the catheter. Incremental dosing through the catheter may also make controlling the change in hemodynamics over a gradual period more achievable with epidural anesthesia.

A "combined spinal–epidural" (CSE) combines the techniques utilizing initial intrathecal SAB with subsequent placement of an epidural catheter in the lumbar region. The catheter is left in place for use if the surgical procedure exceeds the duration of the SAB. The technique is usually accomplished through a specialized CSE needle set that includes a larger gauge epidural Tuohy needle used to identify the epidural space, through which a longer, thinner needle can be passed to enter the subarachnoid space through *dura mater*. The spinal needle is removed after dosing the intrathecal local anesthetics, and the epidural catheter placed for later dosing. A CSE combines the reliability and speed of onset of SAB plus the flexibility of longer term redosing of the epidural catheter.

Tables 8.5 and 8.6 give the approximate duration of spinal and epidural anesthesia using different local anesthetics.

With regards to dermatomal levels for ureteroscopy and PCNL, the neuroanatomic innervations of the renal pelvis and ureters must be considered. Sympathetic innervation of the kidney arises from spinal segments T8 through L1 as preganglionic fibers that synapse in the celiac and aorticorenal ganglia, giving rise to the postsynaptic fibers that travel along the renal artery to

Table 8.5 Dose and duration of local anesthetics used for spinal anesthesia (reproduced from Bernards, C.M. Epidural and spinal anesthesia. In: Barash, P.G., *et al*., eds. *Clinical Anesthesia*, 6th edn. Philadelphia: Lippincott Williams & Wilkins, p. 941, with permission).

		Duration of sensory block		
Drug	Dose (mg)[a]	Two-dermatome regression (min)[b]	Complete resolution (min)[b]	Prolongation by adrenergic agonists (%)[c]
Procaine	50–200	30–50	90–120	30–50
Chloroprocaine	30–100	30–50	70–150	NR
Lidocaine	25–100	40–100	140–240	20–50
Bupivacaine	5–20	90–140	240–380	20–50
Tetracaine	5–20	90–140	240–380	50–100

NR, not recommended.

[a] The lowest doses are used primarily for very restricted blocks (e.g. saddle block), lest they become too dilute to be effective.

[b] Duration is influenced by dose and block height. The duration of surgical anesthesia will obviously depend on the surgical site.

[c] The effect of adrenergic agonists depends on the dose and choice of agonist. Prolongation is greatest at lumbar and sacral dermatomes and least at thoracic dermatomes.

Table 8.6 Local anesthetics used for surgical epidural block (reproduced from Bernards, C.M. Epidural and spinal anesthesia. In: Barash, P.G., *et al*., eds. *Clinical Anesthesia*, 6th edn. Philadelphia: Lippincott Williams & Wilkins, p. 942, with permission).

Text not available in the electronic edition

[a] These concentrations are recommended for surgical anesthesia; more dilute concentrations are appropriate for epidural analgesia.

reach their targets. Renal parasympathetic innervation is from vagal nerve fibers that also travel along the renal artery. The ureters receive their sympathetic input from spinal segments T10 to L2, and parasympathetics from the S2 to S4 nerve roots. Painful stimuli from either distension or mucosal irritation will travel with the sympathetic fibers, as well as the ureters, to radiate up to the level of the upper kidney [57]. For this reason, any neuroaxial anesthetic should cover at least through sensory level T8. This ensures that adequate anesthesia is provided several levels above the surgical site and that skin and chest wall sensory levels above the area where somatic stimulation will occur with instrumentation are also covered (T6).

Physiologic effects of both SAB and epidural anesthesia are similar, although they occur more rapidly with SAB. Cardiovascular effects include decrease in α_1 and β sympathetic stimulation effects ("sympathectomy") from the level of two to four dermatomes above the sensory block level achieved, leading to decreased blood pressure. Venous and arterial blood vessel tone both decrease. The decrease, particularly in venous return, that results can cause a significant drop in cardiac output if the patient is volume depleted [56]. The decrease in systemic vascular resistance can be beneficial for the patient with cardiac disease in that cardiac workload is reduced, if MAP and cardiac perfusion do not also drop excessively. Since cardiac perfusion is heavily dependent on diastolic filling pressure, a significant drop in MAP can have deleterious consequences in those with either significant coronary artery disease or low cardiac reserve.

Table 8.7 American Society of Regional Anesthesia Guidelines (modified and reproduced from Horlocker *et al*. p. 101, with permission).

Thromboprophylaxis	Neuroaxial technique
Antiplatelet medications	NSAIDs: no contraindication Discontinue ticlopidine 14 days, clopidogrel 7 days, GP IIb/IIIa inhibitors 8–48 h in advance
UFH: subcutaneous	No contraindication with twice daily dosing and total daily dose <10 000 U; consider delaying heparin until after block if technical difficulty anticipated.
UFH: intravenous	Heparinize 1 h after regional technique; remove catheter 2–4 h after last heparin dose. No mandatory delay if traumatic
LMWH	Twice daily dosing: LMWH can be resumed 24 h after surgery. Remove catheter 2 h *before* first LMWH dose
	Single daily dosing: neuroaxial technique 10–12 h after LMWH; next dose 4 h after needle or catheter placement
	Therapeutic dose: delay block for 24 h
Warfarin	Normal INR (before neuroaxial technique); remove catheter when INR ≤1.5 (at initiation of therapy)
Fondaparinux	Single injection, atraumatic needle placement or alternate thromboprophylaxis. Avoid indwelling catheters
Direct thrombin inhibitors	Insufficient information. Suggest avoidance of neuroaxial techniques
Thrombolytics	Absolute contraindication
Herbal therapy (garlic, ginseng, ginko)	No evidence for mandatory discontinuation before neuroaxial technique; be aware of potential drug interactions

UFH, unfractionated heparin; LMWH, low molecular weight heparin.

Pulmonary function is not altered clinically during neuroaxial anesthesia in any but those with the most severe pulmonary disease. Tidal volumes are unchanged, and vital capacity decreases slightly during SAB or epidural anesthesia, as a result of paralysis of abdominal muscles. Those with severe respiratory compromise may suffer ineffective cough to clear secretions, due to paralysis of expiratory muscles [58].

Another important issue to be considered with regards to neuraxial anesthesia is anticoagulation, coagulopathy, or antiplatelet therapy, and the risk of epidural hematoma formation. Although rare, if not diagnosed and treated quickly, epidural hematoma can lead to significant permanent neurologic injury, including paraplegia. This is especially pertinent in patients treated chronically with either antiplatelet or anticoagulant agents. According to the American Society of Regional Anesthesia and Pain Management (ASRA), the estimated incidence of epidural hematoma in patients undergoing spinal anesthesia is less than 1 in 220 000, and less than 1 in 150 000 for epidural anesthetics [59]. ASRA recently published “guidelines” on the performance of regional anesthesia in patients on antithrombotic or thrombolytic therapy [59]. Due to the rarity of epidural or spinal hematoma, there are no prospectively controlled data on the subject, and the guidelines are based on case reports, expert opinion, hematology, pharmacology, clinical series, and risk factors for surgical bleeding [60]. The document does caution that it should be considered a “consensus statement” rather than strict guidelines. The risk to benefit analysis must be considered for each individual in light of alternative anesthetic techniques. Table 8.7 summarizes the ASRA recommendations regarding neuroaxial techniques.

Complications and issues for recovery

With both PCNL and ureteroscopy, the acuity of urologic or renal dysfunction due to obstructive uropathy or infection poses challenges to the provision of anesthesia. Decrease in renal function slows clearance and excretion of a number of anesthetic agents and potentiates the duration of action of their active metabolites. Such agents include meperidine, fentanyl, and morphine, and NMB drugs, specifically rocuronium, vecuronium, and pancuronium. This predisposes the patient to prolonged recovery, postoperative mechanical ventilation, and fluid overload. Sevoflurane, a newer inhaled anesthetic, reacts with strong bases and water in the carbon dioxide absorbents when passing through the anesthetic circuit to form Compound A, which has been shown to cause renal dysfunction in animal models. This agent, however, has been demonstrated safe in humans and not shown to cause any more renal dysfunction than other inhaled halogenated agents [61], including in patients with pre-existing renal dysfunction.

Patients with evolving urosepsis pose additional difficulties in that infection and fever increase metabolic rate and oxygen demand. Significant sepsis has been considered a relative contraindication for neuraxial anesthesia (spinal or epidural) for fear of introducing the infection from the bloodstream to the intrathecal space, and causing meningitis; however, that link has never been clearly established and remains controversial [62]. Furthermore, patient comorbidities may influence the surgical and/or anesthetic approach to the stone. For example, patients who need to remain on dual antiplatelet therapy perioperatively for prevention of intracoronary stent thrombosis prohibit neuraxial blockade. Also, many myelopathic patients with chronic nephrolithiasis may have developed tolerance to opioids due to chronic use, which complicates their anesthetic management and recovery.

Percutaneous nephrolithotomy

Surgical complications of PCNL are often minor and include pain (49%), fever (30%), urinary infection (11%), and colic (4%) [10, 63]. Septicemia (4.1%) and bleeding sufficient to require transfusion (2.7%) are the most common major complications of PCNL [63]. Roth and Beckmann cite rare incidences of additional complications in PCNL, including pseudoaneurysm (0.5–1.2%), pelvic or ureteral tears (5–15%), bowel injury (0.1%), pneumothorax or hemothorax (0.1% to 3%), urosepsis (0.3%), MI (0.1–0.4%), and rarely splenic or hepatic injury [64]. When radiographic contrast agents are used, the possibility of allergic reactions to the iodinated dyes must also be considered. Furthermore, latex allergy must be strongly suspected in myelopathic patients who repeatedly self-catheterize to relieve urinary retention, and the operating room must be prepared as a latex free environment. Due to repeated exposures, these patients may be at high risk for anaphylaxis at any point during the procedure [65, 66].

Additional issues complicating PCNL include blood transfusion that may become necessary as a result of pre-existing anemia and/or greater than expected blood loss. An uncomplicated single stage, single puncture PCNL averages very low blood loss; however, there have been incidences where loss of greater than 1 L has been reported [67, 68]. The incidence of transfusion with PCNL lies between 2% and 11%, [36, 64], but may exceed 23% in some groups of patients [67]. Multiple renal punctures and renal pelvic perforation are associated with a twofold greater blood loss [68]. Conversely, the presence of a pre-existing nephrostomy tract decreases this risk by half. Neither puncture site, hypertension, renal insufficiency, infection, nor characteristics of the stone, such as size, location, or composition, increase bleeding risk [67]. Surgery should be rescheduled or, at a minimum, blood for transfusion should be available for patients with pre-existing anemia or coagulopathy. Patients taking anticoagulant or antiplatelet medication require special consideration as the cessation of these medications could have severe consequences [38].

Ureteroscopy

GA for ureteroscopy does present challenges in patients with morbid obesity or multiple medical problems that have a diminished tolerance for the physiologic changes associated with this technique. In patients with severe cardiac disease, sudden hemodynamic changes need to be avoided. Hence, neuroaxial anesthesia *may* be a preferable method of anesthesia [54].

If sepsis is a concurrent issue with the patient, GA or sedation may be a better option to avoid the risk of inadvertent introduction of bloodstream infections into the subarachnoid space as mentioned [20]. Monitored anesthesia care (MAC) may provide heavy sedation but may become GA without an endotracheal tube as the patient loses consciousness (Figure 8.2). Several agents are typically utilized for this technique, and include a combination of narcotics and sedative hypnotics where the desired effect of each medication is potentiated and negative side effects minimized, provided there is effective renal clearance. For example, utilizing remifentanyl, propofol, or dexmedetomidine with a combination of narcotics or benzodiazepines for heavy MAC/sedation, either individually or in combination, has been shown to decrease anesthetic induction and postoperative recovery times during lithotripsy [65]. Rapid recovery, however, is dependent upon adequate redistribution and elimination of these agents, as well as their active metabolites. Excretion of these active metabolites is largely dependent upon adequate renal function. This is especially important for narcotics such as morphine, hydromorphone, and meperidine, as well as many NMB agents.

Conclusions

Anesthetic techniques for ureteroscopy and PCNL must be planned based on patient comorbidities, details of surgical anatomy, as well as surgeon and anesthesiologist preference. Multiple techniques have been used successfully and safely. Many patients with nephrolithiasis have multiple comorbidities that need to be considered. Examples noted include diabetes, hypertension, and obesity. Lastly, positioning for PCNL adds an element of complexity for which careful preoperative planning is required.

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CHAPTER 9

Organizing the Operating Room for Percutaneous and Ureteroscopic Procedures and Laparoscopy

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Introduction

The working of the operation room (OR) needs specialized planning and execution. A combined "civil–mechanical–electrical–electronic–biomedical" combined effort is required, coordinated by the needs, preferences, and safety of the medical/surgical team. Apart from the scarcity of practical publications and details in this area, the highly technical nature of many of the issues, and the difficulty of communicating them, often result in mistakes in planning being made at a very simple level.

OR complexes are designed and built to carry out investigative, diagnostic, therapeutic, and palliative procedures of varying degrees of invasiveness. Since the introduction and widespread application of minimally invasive surgery, the design of a modern OR has changed dramatically. Adapting the modern OR for endourology is a challenge that begins with the more general problem of designing the OR. There is a need for safety, convenience, and economy in planning a dedicated endourology fluoroscopy-compatible OR complex. It is necessary that planning is perfect, keeping in mind future needs, as subsequent changes or renovations are tedious and pose tremendous economic burden [1].

In the current era of information technology, audiovisual (AV) recording, and telementoring have become a frequently used teaching and training aid in operative surgery (see Chapter 3). Most surgical meetings today devote a major session to the live operative workshop. Unfortunately, many video recordings are of poor quality, and often, because of the constraints of the equipment and the operating environments, do not demonstrate the principles of the technique as well as the presenter intended. The other problem is economic restriction, especially in semi-government aided or private hospitals. These shortcomings are severely felt, especially in a tertiary care teaching hospital, as surgical workshops are held quite regularly and AV transmission consumes a large chunk of the investment. In addition to being used to relay the operation, the teacher can access the video display to monitor the progress of the operation, and it can be used to teach residents in the OR about the procedure.

In this chapter, we intend to present a comprehensive description of the planning of a state-of-the-art endourology-dedicated OR, with both high-class OR equipment and technology-driven OR data management.

Designing and planning a dedicated operating room

The design and layout of the OR room is extremely important. The state-of-the art design enables hassle-free movement of equipment, surgeon ease in viewing multiple screens, and efficient data archival, management, and relay system. It is necessary to anticipate the average number of procedures that will be carried out. It is better to plan bearing the next 10 years in mind.

Meeting these challenges requires a multidisciplinary team and a well-planned process that addresses all aspects from long-term goals to exacting details. Design and construction firms apply experience and expertise

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to handle the intricacies of the dedicated OR. Select an architect and construction manager with considerable healthcare experience, including of surgical suites and ORs. Architect, engineer, equipment planner, construction manager, and key equipment vendors should all be included in the team [2]. Strategic equipment placement is essential to increase efficiency and safety within the surgical space. Equipment booms and other ceiling-supported equipment are used increasingly in ORs because of the advantages they offer [3]. Equipment booms are ceiling-mounted, articulated arms that support much of the OR equipment, like lithotripters, light sources, endocameras, electrocautery equipment, anesthetic gas connections, and electric plug points. The booms, which can move in every direction, significantly reduce clutter and interconnect equipment, freeing floor space and simplifying cleaning. They utilize the space above the false ceiling, thereby enhancing sterile set-up and reducing maintenance as a result of cable breakage. Booms, however, require a significant amount of structural support, which must be coordinated with the lighting, mechanical, and electrical systems above the false ceiling.

General design for a fluoroscopy-compatible endoscopic operating room

Size

The size of a general OR is 20 × 20 × 10 feet. Since endourologic procedures use large equipment, like a C-arm, laser, ultrasound machine, and workstation, the recommended size of a dedicated endoscopic OR is 23 × 23 × 12 feet.

Ceiling

The floor-to-false ceiling height should be around 12 feet. The overall height of the OR should be around 14 feet to give an over-ceiling space of 2 feet. Individual cassettes made of painted sheet steel are clipped into the grid to form a suspended metal ceiling. The individual cassettes can be removed and reinstalled to permit maintenance and refitting work.

The over-ceiling plan is an important feature. This space includes:

- Cables for various multiple equipment booms, such as oxygen, nitrous oxide, compressed air, vacuum, electrical wires.
- Air conditioning pipelines. The ceiling air supply with the sterile air distributor is one of the most important elements for hygiene in the operating room. Bacteria, viruses, and dust particles are trapped immediately before the air enters the room. The sterile air distributor generates a homogenous and low-turbulence displacement flow. The inner air supply area remains free from contaminants drawn in from the room environment. In this way the area around the operating table is kept in a high state of cleanliness during the operation, with an extremely low pathogen level of less than 10 colony-forming units/m^3. The sterile air distributors can be easily detached or swung away for quick and economic filter changes.
- Data relay wires in various hanging arms.

Pendant services

Two ceiling pendants for pipeline services should be designed; one for the surgical team and one for the anesthesiologist. The anesthetic pendant should be retractable, have limited lateral movement, and provide a shelf for monitoring equipment. It should have oxygen, nitrous oxide, four bar pressure medical compressed air, medical vacuum, scavenging terminal outlets, and at least four electric sockets. The surgeon pendent or cart should have the capacity to hold video camera electronics, a light source, and various recording devices such as a VCR, printer, or video disc recorder. Moreover, some carts also have room to hold the laparoscopic insufflator and electrocautery units.

Floor

There should be a central drain outlet from the floor, centered underneath the OR table. The floor should have a slight tilt from all the walls, converging at the water drain outlet. The floor surface must be slip resistant, strong, and impervious, with minimum joints, e.g. mosaic with copper plates for antistatic effect or jointless conductive tiles/terrazzo, linoleum etc. The recommended minimum conductivity is 1 mOhm and maximum 10 mOhm.

Walls

The radiation protection of a general-purpose fluoroscopy suite necessitates a wall thickness in all directions equivalent to 2 mm of lead (15 cm of concrete or 25 cm of brick with plaster). While lead is always accepted as the standard material for radiation protection, ordinary building materials may be equally suitable provided they are thick enough. As for the floor, the surface of the walls must be slip resistant, strong, and impervious, with minimum joints. Laminated polyester or smooth paint provides a seamless wall surface; tiles can break and epoxy paint can chip. Light color (off white, light blue or green) washable paint is ideal. There should be provision for an X-ray film illuminator, wall-mounted camera, plasma screen, and drawers for endoscopic disposables, recessed into the wall.

Main door

The main door to the OR must be of adequate width (1.2–1.5 m) to facilitate smooth patient trolley, laser, C-arm unit, and ultrasonography machine entry and exit. Sliding doors are preferred as these do not generate air currents.

Lighting

Different levels of lighting are necessary in the OR and a means of dimming light may be needed during endoscopic procedures. The flat TFT monitor display for endocamera vision requires the installation of dimmable lighting to create optimum light levels. Color-corrected fluorescent lamps are preferred to produce even illumination of at least 500 Lux at working height, with minimal glare. In the operating area, overhead light should be shadowless and give 25 000–125 000 Lux of light (50 000–100 000 Lux at the center and at least 15 000 Lux at the periphery), as in the general OR. Light emitting diode (LED) light provides a unique multicolor temperature facility, which proves helpful during open surgery, which may be required in the event of an endoscopic complication. LED light has the advantage of lower heat generation, adjustable light characteristics, and unlimited lifespan. Lights should be freely movable both in the horizontal and vertical planes, and for this movement equipment booms are generally preferred.

Operating room table

The OR should have a mobile, modular operating table with electronically controlled hydraulic drive, battery and mains operation, and of adequate width and weight-bearing capacity. It should have a stable base construction, rotatable, top and large twin disk castors for easy maneuverability. The operating tabletop needs to be subdivided into multiple sections; head plate, upper back plate, lower back plate, seat plate, and leg plates for lithotomy position. To be compatible with fluoroscopy, the entire tabletop should be devoid of cross bars. Provision for kidney bridge elevation is helpful if open exploration is required. There should be multilayered radiolucent foam padding for patient comfort and safety.

C-arm

A mobile C-arm unit is essential in an OR dedicated to urology. It should have balanced and graduated movements at any angle. It should provide a high-quality image to allow quick and precise diagnosis (brightness should be monitored so that image quality is not affected by changing lighting environments). Functions of the image intensifier should include DICOM imaging capabilities, last image hold memory, image processing, and text/graphics. Image display should be on a high-resolution TFT monitor. The data output from the C-arm may also be connected to one of the hanging screen monitors so as to be in easy view of the operating surgeon.

Sterilization (see also Chapter 1)

There should be a separate room for cleaning and disinfection of endoscopic instruments, which should have adequate ventilation to exhaust toxic vapors and airborne pathogens. Automated processing disinfection machines for endoscopic instruments are desirable. However, there should also be provision for manual rinsing and cleaning. If endoscopes and other accessories cannot be autoclaved, there needs to be provision for chemical sterilization and ethylene oxide (ETC). Endoscopic procedures need delicate and expensive equipment, like telescopes, flexible ureteroscopes, and flexible nephroscopes. Rapid sterilization is required if many procedures are to be performed in a day, and for this we recommend a Sterrad sterilization system close to the OR, which provides a high level of sterilization within a processing time of half an hour.

Operating room configuration for endourologic procedure

This configuration of an endourology OR is different from that of a general OR, as equipment has to be strategically located. This will minimize procedural time by allowing intuitive control and shorter changeover times, as equipment settings can be freely defined and activated. The OR should integrate cameras, lights, video conferencing units, endoscopic and anesthetic equipment, C-arm and the operating table, and all should be capable of being operated from the sterile area.

The anesthetic trolley should be movable on a mobile cart supported by the anesthesiologist's equipment boom, and located at the cephalad end of the patient on the same side as the procedure.

There should be a minimum of three hanging display screen monitors, supported by a boom, moveable in all directions, and placed in front of the surgeon (Figures 9.1 and 9.2). The display monitors should be interconnected with changeable viewing between fluoroscopic image, endovision image, ultrasound image, and HIMS image (Hospital Information Management System).

Quite often both kidneys need to be operated on under the same anesthesia. This can be done in two ways. In the first, the C-arm unit remains fixed while

Image not available in the electronic edition

Figure 9.1 Surface view of a dedicated fluoroscopy-compatible endourology operating room (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission). For explanation of numbers, please see the key to Figure 9.2 opposite.

the anesthesia boom and table rotate through 180°. In the second, the anesthesia trolley and table remain fixed, while the surgeon's position changes. Display screens accordingly also change the direction in which they face. The light cable source, lithotripsy device, endocamera cable, and irrigation tubing are attached to the equipment boom on the right side behind the surgeon.

Figure 9.2 shows the essentials of a strategic equipment set-up for left percutaneous nephrolithotomy (PCNL).

Modular operating theatre

The prefabricated modular operating theatre offers the advantage of speedy construction combined with design of the highest quality and standards, while allowing for future expansion and development in surgical technique. The standard package includes an operating table, operating lights, endoscopy equipment, and a range of monitors that surround the patient [4].

Two dedicated endourology modular ORs are currently available, one from Karl Storz (KARL STORZ OR1™) and the other from Richard Wolf GmBH (CORE™), which can be installed on demand by the respective technical teams. The KARL STORZ OR1™ provides the modular operating room layout for performing minimally invasive endourologic and laparoscopic procedures. Key features include optimal picture quality from various camera systems and other signal sources, integration of Karl Storz endoscopic equipment, the full range of functions of devices and peripheral systems made by other manufacturers, such as the OR table and room lighting, and simple and secure documentation of intraoperative recordings and the OR environment at a central location.

CORE™ has a modular, networked structure to link various devices in the operating theatre. The system provides interactive monitoring and centralized control from a single operator panel, and has speaker-independent voice control that enables devices such as cameras, lights, video conferencing units, PACS, high-frequency equipment, room functions, and the operating table to be operated from the sterile area. Medimage, a digital patient imaging and document management system, facilitates intraoperative visualization of preop-

Image not available in the electronic edition

Figure 9.2 Strategic equipment placement in a case of percutaneous nephrolithotomy (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission). 1, X-ray screen in wall; 2, plasma screen; 3, drawers recessed in wall; 4, electronic work station; 5, HIMS computer; 6, speaker; 7, camera 1; 8, camera 2; 9, camera 3; 10, OR LED light 1; 11, OR LED light 2; 12, hanging screen 1; 13, hanging screen 2; 14, hanging screen 3; 15, boom for hanging screens; 16, ultrasound machine; 17, C-arm; 18, LASER machine; 19, anesthesia boom; 20, anesthesia trolley; 21, OR table; 22, equipment boom; 23, endoscopic instrument; 24, nurse trolley; 25, surgeon; 26, assistant; 27, nurse.

erative image data on monitors located within the operating area.

Data management (see Chapter 3)

In the current era of information technology, data capture, archival, and relay have become a frequently used teaching and training aid in operative surgery [5]. The ability to project computer and video information to a class or auditorium is now almost essential in many tertiary care hospitals, driven by the exponential increase in computer usage by both teaching staff and students. This need for versatile, large-screen electronic display systems is the dominant factor influencing the design of AV facilities, and typically the most expensive single equipment element of any presentation system. Other technologies have grown up around the electronic display capability, and the expectations of users have become more sophisticated.

Data capture

A surgical video system (SVS) is an integration of components used to perform minimally invasive surgery. In the operating room, an SVS consists of an endoscope, attached video camera, light source, video processor, and one or more video displays.

Endoscope

Digital videocystoscopy and ureterorenoscopy use high-resolution monochrome CCD chip technology [5]. Three-chip systems provide better overall image quality than one-chip systems. The use of high-definition cameras and monitors during minimally invasive procedures can provide the surgeon and operating team with more than twice the resolution of standard definition systems. If a high-definition camera is selected, it is imperative to invest in computer hardware and software capable of editing and outputting high-definition video.

video camera

There are many options for avoiding poor quality video capture in surgical procedures on the body surface. The simplest and most cost-effective method in this setting is to employ a video camera mounted on a tripod (surface camera) or installed on the wall with movable pulley (overhead camera). These are available from any number of consumer electronics outlets and in a variety of formats. Although it is possible to obtain reasonable quality video recordings by using the automatic exposure settings on most cameras, this often requires diversion of the operating light away from the operative field to avoid overexposure of the image. Almost all cameras, however, will have a predefined setting for bright environments, and this is an ideal alternative to use in this situation.

Video light source

Additional advances in imaging have resulted from the use of a high-intensity light source, generated from either halogen or xenon sources. The ability to adjust light intensity using several mechanisms has been a recent advance. Newer CCDs or image sensor-based endoscopic cameras feature electronic exposure. Recent innovations in illumination technology use single- or multi-point shadow-inducing systems.

Video and image capture

When performing endourologic surgery, video capture is not usually an issue. A signal can be taken directly from the lineout plug of the camera-processing unit and inputted directly into an analog or digital VCR using an s-video connection. Some endoscopic video processors come equipped with digital video (DV) outputs which capture a high-definition video.

Of importance in a dedicated OR is an efficient to-and-fro data capture for HIMS. HIMS uses a network of computers to gather, process, and retrieve patient care and administrative information for all hospital activities to satisfy the functional requirements of all those involved in the care of patients. It is also helpful to the hospital authorities for developing comprehensive healthcare policies. HIMS incorporates an integrated computerized clinical information system for improved hospital administration and patient healthcare. It also provides an accurate, electronically stored medical record of the patient. There are innumerable software packages currently available for installing HIMS as per local preferences. The software has to be installed on all computers in the OR complex. A separate hardware for HIMS exists which has output for s-video and composite video. The output is connected to the OR panel and through it to the various data capturing units working during the procedure. In this way, multiple images and videos can be captured and stored in the patient data file for future references in HIMS. SVSs integrate a digital image capture system that allows the immediate capturing of still images from endoscopic procedures. A less expensive alternative is the digital still image capture adapter, which can be connected to endoscopic camera systems. Digital still images usually can be recorded in JPEG (.jpg; Joint Photographic Experts Group), TIFF (.tif; tagged image file format), or BMP (.bmp-bitmap) formats, depending on the necessary quality of the image to be edited (see Chapter 3).

Data archival

Customized OR software can be designed for individual needs. The following provides a general outline of the requirements of a data management system.

Workstation

In the modern OR, there should be an electronic workstation located in one corner. This workstation (Figure 9.3) has inputs via cables connected to the surface cameras, C-arm, ultrasound machine, and endovision camera. The cable input enters the OR panel where the composite AV signal is converted to s-video signal. The s-video output can be transmitted to any of the hanging display monitor (TFT screens) in front of the surgeon. Each screen has multiple cables, hence any image (fluoro/ endovision/HIMS) can be viewed on any screen. The workstation also has a video processor with digital video (DV) output. High-definition video [6] is thus captured and recorded on DVD for archiving and future editing. The OR panel is also connected via a two-way circuit to HIMS. The necessary information, including the history, examination, X-ray, and CT scan images can be relayed to the hanging display monitor in front of the surgeon during the operation. At the same time, the OR details can also be fed to HIMS for data archival. The workstation has three ISDN line connections.

Data capture

Endovision camera

A signal can be taken directly from the line-out plug of the endocamera processing unit and inputted directly into an OR panel on the workstation.

Surface camera

At least three surface cameras should be present in the OR for video capturing [7]. One camera is directed at the tabletop, and may be mounted on a light source or on a hanging boom. Another camera should be wall mounted near the ceiling, and provides a view of the complete OR. This camera can be zoomed in or out as required by remote control. The third camera should be on one of the TFT screens. This position captures the face of the surgeon and is important during video conferencing when the surgeon is performing the procedure while watching the screen and simultaneously

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Figure 9.3 Data management through the operating room workstation. USG, ultrasound guided (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission).

talking to the audience in the auditorium; these images will give the impression to the auditorium that the surgeon is facing and talking to them.

Fluoroscopic and ultrasound image

Most C-arm unit [8] and ultrasound machines have a coaxial output jack on the back of the device. To arrange for data transfer, the coaxial jacks need to be connected with a coaxial cable and connected to the OR panel.

Data relay

Various aspects need consideration for a state-of-the-art transmission relay system. Preliminary knowledge of the individual components of the relay system is essential for optimum utilization. These can be divided into components of local data relay and of the local and distant data relay system.

Local data relay components

The relay components are electrically interfaced to a control station within the OR. This control station has the capability to route voice, video, data, and physiologic information to and from the surgical suite. This capability is achieved through strategic equipment placement and an electrical infrastructure that allows the distribution of power and low-voltage wiring. Information is not only distributed within the operating room but also to remote locations such as image archiving systems (PACS), classroom, and auditorium.

Modulator

The AV signal is converted into a UHF signal so that it can be received through a TV antenna input. Various electronic modulators are commercially available.

- *Combiner* has two inputs that respectively receive an NTSC combined visual and audio signal and a DTV signal wherein the NTSC signal and the DTV signal are in adjacent channels. The combiner has sharply tuned filtering interposed between the inputs and the output, tuned to pass the DTV signal while reflecting the NTSC signal such that these combine to form the combined output signal.
- An *RF amplifier* is used to convert a low-power radiofrequency signal into a larger signal of significant power.
- *Audio mixer* is an electronic device for combining, routing, and changing the level, tone, and/or dynamics of audio signals. The modified signals (voltages or digital samples) are summed to produce the combined output signals.

- *Video mixer* is an electronic device used to combine or "mix" two or more (PAL or NTSC) video signals, then output the sum as one new composite video signal. The picture-in-picture (PIP) and picture-on-picture (POP) support unit allows users to watch TV channels or DVD movies together with the computer screen, if a PC is connected to this unit. The PIP zoom function allows the PC image to occupy the main screen, with a video subwindow inserted. This video subwindow can take one of three sizes: one-quarter, one-ninth, or one-sixteenth of the screen, and can be relocated anywhere on the screen. POP is designed for cable TV channel preview. The channel preview can be set as 3 × 3 or 4 × 4 matrix with up to 16 channels at a time.

Optical fiber composite overhead ground wire

This type of cable (OPGW) is used in the construction of electric power transmission and distribution lines. The optical fibers within the cable can be used for high-speed transmission of data. Because of the physical properties of image transference, optical fiber has a lower attenuation than coaxial cable and is not subject to electromagnetic interference.

Wireless local area network

Using electromagnetic waves, these networks (WiFi) allow wireless devices to communicate with one another through access points or antennae. The advantages of a wireless network are the lack of having to install a wired network and the ability to communicate with mobile users.

Local operating room data relay system

Most surgical meetings today devote a major session to the live operative workshop. Preliminary knowledge of the individual components of the relay system is essential for optimum utilization.

Control room

A small control room in the vicinity of the operating room is useful for the data relay system. The control room receives cable connection from all of the data capturing components, and can route voice, video, and data to and from the surgical suite. Information is not only distributed within the OR but also to remote locations such as image archiving systems, classroom, and auditorium. One such electrical circuitry is shown in Figure 9.4.

To channel transmit OR proceedings to remote places, the composite AV signals from the OR is first relayed via cables to the control room. Here the signal is passed through the modulator, combiner, and video mixer (Figure 9.5). The emerging RF signal is thus transmitted to remote places, such as the plasma screen recessed in

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Figure 9.4 Data management through the control room, USG, ultrasound guided (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission).

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Figure 9.5 Local data relay flowchart. To and fro local data management: There are four endourology theaters depicted in the OR complex. Each OR has four outgoing optical cables (colored red, green, purple, and light blue) two endovision screens, fluoroscopic image and ultrasound image. There may be multiple outgoing cables depending on the needs of the hospital. There are two incoming cables (colored blue for RF signal and brown for audio) (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission).

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Figure 9.6 Data relay from the auditorium. RF, radiofrequency (reproduced from Sabnis, R.B., Mishra, S., Sharma, R.B. Preoperative planning and designing of a fluoroscopic endourology operating room. *J Endourol* 2009;23:1579–1585, with permission).

the wall of the OR. The operating surgeon through the microphone can interact with observers at remote places in a similar way. As described above, advanced video transmission features can be incorporated in the relay system; PIP and POP.

Similarly signals can be relayed from remote places to the OR (Figure 9.5). For example, the AV signal from the auditorium is sent to the modulator in the auditorium and the emerging RF signals are then relayed to control room (Figure 9.6). The signal is then sent to the modulator, combiner, and audio mixer. The final amplified RF signal can be relocated to any remote place, including transmission to the plasma screen in the OR.

Four clinical scenarios for local data relay are shown in Figure 9.5. The first shows a teacher in a remote location accessing the live operative video display to monitor the progress of an operation. The AV signals from the OR are relayed to the video mixer and modulator. The signal from the modulator is mixed in the combiner and the emerging RF signal is transmitted to the teacher's room. The teacher can order specific commands about the procedure from this remote location to the operating resident in the OR through a wireless microphone. The audio signal is relayed to the audio mixer, and then to the speaker installed in the OR or through the modulator, which creates the RF signal that is relayed into the OR through the installed LCD screen.

The second scenario shows a teacher who is operating in the OR and relaying AV signals to the classroom or the auditorium for a two-way interactive operative workshop. Here, the AV signal is relayed to the video mixer for POP support or directed to the video modulator and combiner. The selected signal is amplified, switched into an RF signal, and transmitted to the plasma screens or projectors in the auditorium or classroom. The audio feedback from the audience is collected through the microphones and relayed to the audio mixer. After passing through the modulator and combiner, the RF signal is displayed on the LCD screen in the OR or, after passing through the audio switcher, an audio signal is relayed through the speaker installed in the OR.

The third scenario shows a teacher or observer who is remotely monitoring the progress in various ORs. The video signal from the various ORs is transmitted to the modulator and combiner, and as an RF signal is then sent to the teacher. The teacher can select the individual OR they wish to monitor using a channel selector.

The last scenario shows a surgeon who wishes to watch the OR proceedings on DVD. The video signal from the OR is fed into the video mixer. The output signal is then recorded by the DVD recorder, and a DVD can then be given to the surgeon to watch.

For teleconferencing to distant places and countries, an ISDN network facility needs to be connected to the computer in the workstation in the OR. Just like a regular telephone line, the ISDN enables the OR transmission to be dialed to any ISDN location anywhere in the world. Through the B channel, the ISDN line can support simultaneous two-way communication for two devices, such as a computer and a telephone, or a computer and a video camera for teleconferencing. Through the ISDN line, data can be sent to remote locations and at the same be received by the workstation, sent to the control room, and then transmitted anywhere else required.

Conclusions

A dedicated OR design is essential for endourology and allows efficient state-of-the-art care in the modern information technology era. The older cart-based paradigm restricts the ergonomic configuration of the OR and creates potential mechanical, electrical, and biologic hazards to the patient and OR staff. In order to decrease clutter, ease personnel movement, improve ergonomics, maintain the sterile field, and facilitate the use of advanced imaging, an appropriately designed OR is essential. These design elements may prove to be critical to the next generation of dedicated fluoroscopy-compatible endourology suites, and will facilitate further advances in procedures.

The data archival, management and relay system enables efficient and cost-effective transmission of data. This arrangement has been used extensively in our own hospital during the last 5 years, with resultant high-quality video recordings being presented at a number of national and international surgical meetings. In addition to being used for recording video, members of the OR staff can refer to the video display to monitor the progress of the operation, and it can be used as a teaching aid for residents present in the OR during the procedure.

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PART 2 Patient Positioning for Percutaneous Access

CHAPTER 10

Patient Positioning for Supine Access

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Introduction

It was in 1954 that Wickbom [1] performed the first antegrade pyelography by direct renal pelvis puncture [1], and the following year Goodwin *et al*. reported the first percutaneous nephrostomy in hydronephrotic kidneys [2]. At that stage radiologists considered that the overdistended kidney pelvis could most directly and easily be accessed with the patient in the prone position.

In 1976 Ferstrom and Johannson extracted the first kidney stone after multiple dilation sessions of a percutaneous tract [3]. A few years later, Karamcheti and O'Donell [4], Smith *et al*. [5], Wickham and Kellet [6], Alken [7], and other urologists learned and perfected the percutaneous nephrolithotomy (PCNL) technique, but not the puncture procedure. They continued to follow the primitive advice of radiologists.

In the late 1980s, after having performed some corpse dissections and computer axial computed tomography (CT) checks, we described PCNL with the patient in the supine position, and the multiple advantages of this position for endourologic surgery [8, 9] (Figure 10.1). We demonstrated out technique, sometimes using live surgery, at many international congresses, meetings, and courses, convincing a few urologists to adopt this approach. In the *Journal of Endourology* we asked the question, "Why is percutaneous nephroscopy still performed with the patient prone?" [10], and showed a radiologic intraoperative image of simultaneous access to the kidney (transureteral and percutaneous) with rigid instruments, but still this did not recruit more followers. It was only by the time of our article in the *Journal of Urology* in 1998 [11] that this position had become more widely used internationally, but use was still limited in the USA.

Today PCNL in the supine position has attracted much interest, and the number of urologists who recognize its multiple advantages is increasing.

Supine positioning

It is advisable that the surgical table is radiolucent, with articulated leg supports; thus, the patient can lie in a pure supine position or with their legs separated and flexed. In both cases, a 3-L water or air bag is situated under the lumbar fossa of the target kidney (Figure 10.2; see Video 10.1) It is important that the edge of the bag and the patient's flank are alongside the surgical table edge, in order to facilitate the free movement of the nephroscope (see Video 10.1). Some nephroscopes are short (<20 cm) and are not recommended, as they receive light and water connections from opposite sides, which causes problems for the positioning of bag or the patient's hip, and obstructs the tilting movements of the endoscope.

The patient's legs may be extended (with their feet oriented upwards or slightly obliquely) (Figure 10.3), or flexed on leg supports. If the latter, we prefer to set the contralateral leg lower to facilitate the ureteral access with a rigid ureterorenoscope (Figure 10.4). (see Video 10.1). The ipsilateral arm of the patient is flexed and fixed onto their thorax with adhesive drape.

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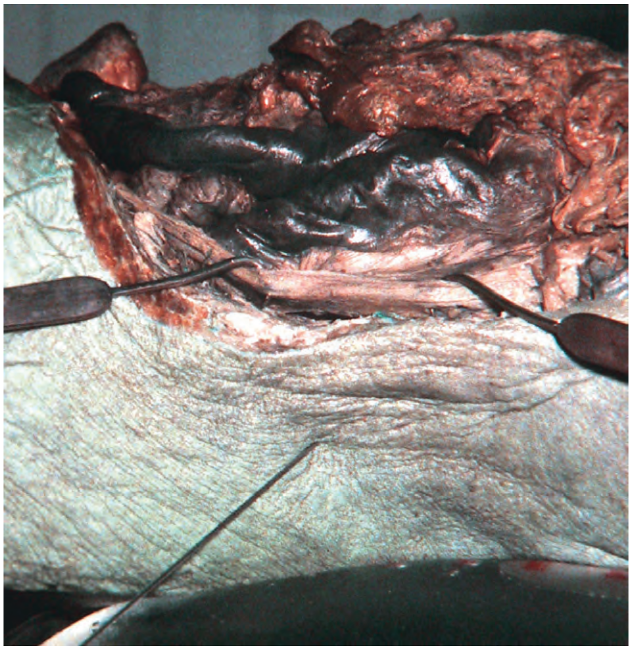

Figure 10.1 Corpse dissection. Two hook separators depress the Toldt line and this ensures that the needle does not touch either the peritoneum or colon.

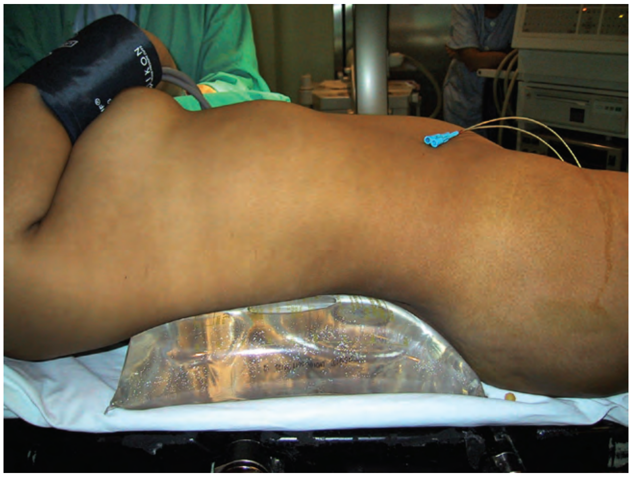

Figure 10.2 Lumbar fossa is draped over the 3-L sac right at the edge of the table.

Variations

Some modifications of this position have been described. Some urologists prefer to rotate the patient a little more [12]. In this case, the direction of the tract is more horizontal and the entrance skin point is slightly more distant from the 3-L bag.

Some urologists prefer to maintain the oblique position of the patient by means of two bags or gel pads, one underneath the shoulder and the other underneath the hip. In their opinion, this procedure allows for larger nephroscope movements [13].

Others prefer the pure supine position, without any element of suspension under the lumbar fossa [14–16]. In these cases it is preferable to use a special surgical table, without any metal bar on its lateral edge. Then, the flank of the patient can be positioned at the table edge and freedom of movements is maximized.

Finally, others prefer to position the patient with their legs flexed on supports, but with the ipsilateral leg lower and more extended [17].

As we have described previously [10, 11], when we have needed to perform PCNL with simultaneous rigid ureterorenoscopy (URS) , we position the patient with their legs flexed in supports, with the ipsilateral leg more elevated and the contralateral more descended, because we consider this position to be more physiologic with less force on the patient's waist. In the early years of the rigid URS, Pérez-Castro and Martinez-Piñeiro [18] described how it was easier to work with the patient's legs in this position, without any interference. Futhermore, today with the video camera attached at the ureterorenoscope optic, no force needs to be applied to the patient's legs in this position.

When we consider it will not be necessary to perform a rigid URS simultaneously with PCNL, we prefer to position the patient with their legs extended. In this position it is also possible to perform ureteral catheterization or URS with a flexible instrument. However, as ureterenoscopes are actually semi-rigid and very thin, we more frequently use simultaneous access.

Puncture technique

With the patient in the supine position it is easy to explore the kidney with an ultrasound 3.5-MHz probe and calculate the direction in which the needle must be inserted. Futhermore, if the ultrasound probe has a puncture channel, it is possible to use ultrasonography to guide initial access. Nevertheless, this requirement is not necessary and we almost never use it.

With this technique it is possible to puncture the calyceal papilla without having to rotate the C-arm fluoroscope. Initially we superimpose a long metal instrument (e.g. a nephroscope or stone grasper) on the patient's abdomen and under fluoroscopic control place its distal tip over the selected calyx (Figure 10.5; see Video,10.1). Then we mark this point on the sterile drape as it indicates the orientation of the needle. With this maneuver we also know where the skin entry point will be situated (between the 12th rib and iliac crest). If necessary, the puncture can also be between the 11th and 12th ribs (Figure 10.6).

The skin entry point must be situated one or two fingers above the 3-L bag. This point is always behind the posterior axillary line (see Video 10.1). For those performing their first cases, it is advisable to draw the

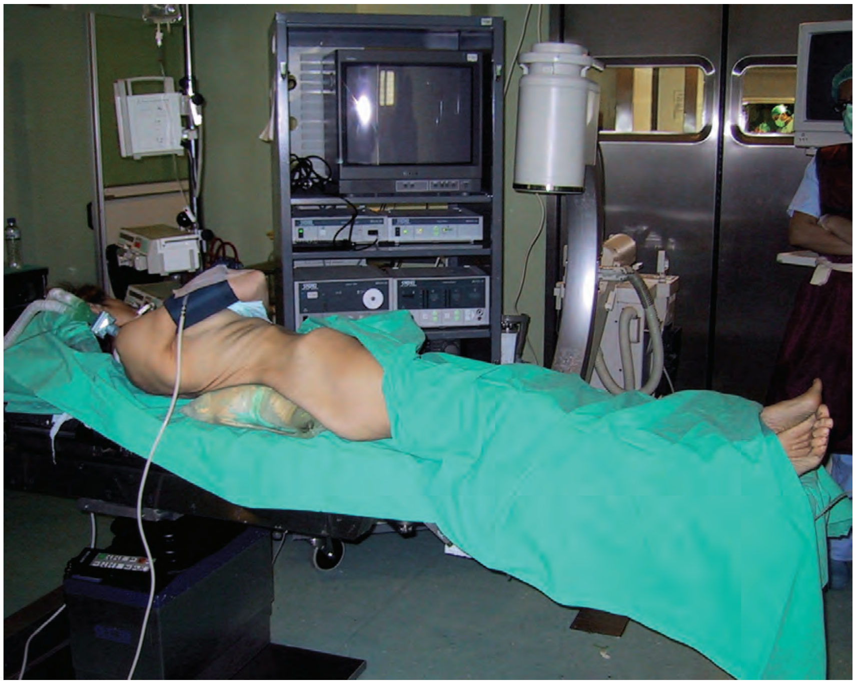

Figure 10.3 Patient's legs are completely extended. Note that her feet are not in a lateral position.

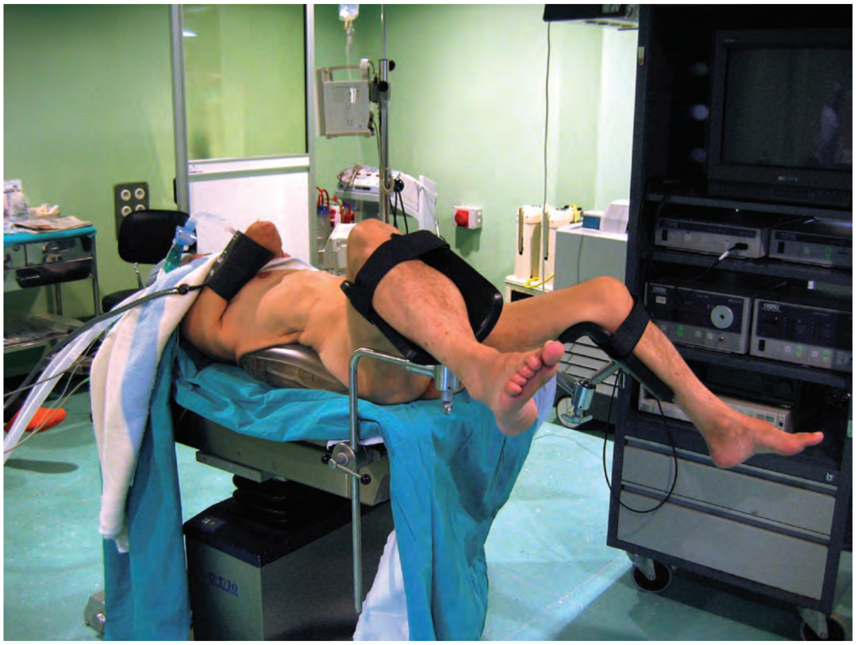

Figure 10.4 Mixed position. Patient's legs are flexed on supports, but with the contralateral leg lower to facilitate ureteral access using a rigid ureterorenoscope.

axillary line on the patient's skin when they are either sitting or standing up, with their arms extended and hanging down. If the line is drawn when the patient is already lying down on the surgical table with the 3-L bag under their lumbar fossa and their arms crossed and flexed over the chest, the position of the line will appear too far forwards.

After having crossed the skin and muscular layers with the needle in an ascending direction (see Video 10.1, we wait for the moment when the selected calyx is well distended with contrast, and then palpate the renal capsule with the tip of the needle. If we have a good response from the kidney (i.e. backward movement and in some cases distortion of the calyceal cup), we advance

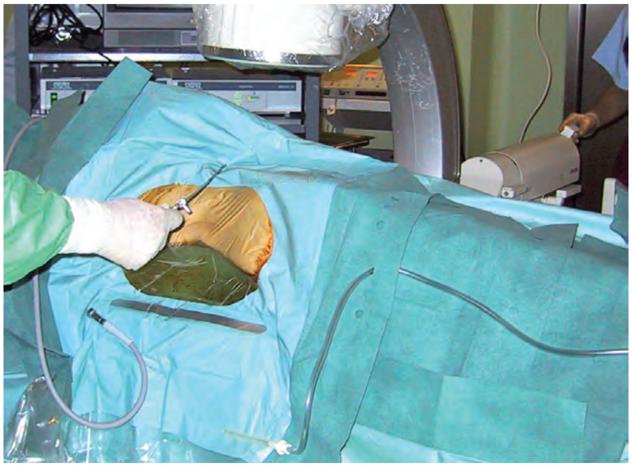

Figure 10.5 A nephroscope stone grasper is superimposedon the patient's abdomen and fluoroscopy is used to guide the positioning of its distal tip over the selected calyx.

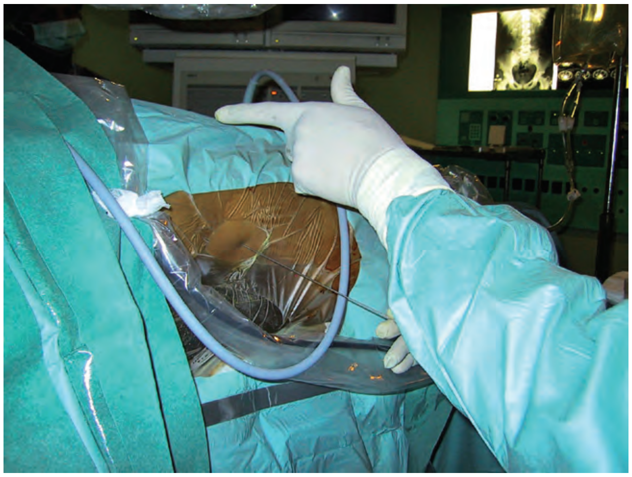

Figure 10.6 Finger pointing to the previously marked point in the sterile drape. The needle penetrates the skin over the serum sac, two finger breadths away from the marked point, and is then directed in an ascending direction to this point.

the needle and penetrate the calyx. If not, it is necessary to retract the needle from the kidney and try and palpate it again in a higher or lower direction (see Video 10.1).

In some cases, when puncture fails, before extracting the needle, it is possible to move the needle upwards or downwards under fluoroscopic guidance. If the contrast filling the calyx is displaced when the proximal tip of the needle is manipulated, it is because the needle is situated underneath the calyx and its tip is compressing the calyx. In this situation, the needle must be extracted from the parenchyma, and a new attempt at puncture made, but this time directing the needle's tip higher. Incorrect punctures are usually due to the fact that the puncture is in a horizontal instead of in an ascending direction.

When the selected calyx has been reached and the first urine drops are obtained through the needle, the guidewire is introduced and the tract can be dilated, initially by means of a thin flexible Teflon dilator and then with the Alken telescope set or a balloon dilator set (see Video 10.1).

With these few tricks it is possible to puncture the selected calyx without having to make complex angle calculations while rotating the C-arm fluoroscope.

Advantages of the supine position

Supine access is more comfortable and safer for the urologist, because they can work in a sitting position and their hands are never in reach of the X-ray.

Calyceal puncture is easier than when the patient is in the prone position. With the supine position, the incidence of the X-ray is perpendicular to the needle and calyx axis, and displacements of the calyceal papilla are better appreciated when the tip of the needle is pushing in front of them, making it unnecessary to rotate the C-arm fluoroscope (see Video, 10.1 another example; puncture 3).

There are no iatrogenic risks, because it is not necessary to change the position of the patient, in whom an endotracheal tube, urethral sound, ureteral and intravenous catheters, some electrodes, etc., will have been inserted, and time is not expended on this maneuver.

In the pure supine position, it is possible to insert a ureteral catheter by means of a flexible endoscope.

In the supine position, intervention is better tolerated by high-risk patients, especially the old and obese, because the vena cava is not compressed and the diaphragm is not pulled up. Moreover, in obese patients, the fat apron displaces towards the contralateral side, thus reducing the distance from the skin to the kidney.

All patients will be more comfortable in the supine position. In certain cases, it is possible to perform PCNL with regional or even local anesthesia, complemented by intravenous sedation. In the event of any complication, the supine position will mean the anesthesiologist can introduce without problem an endotracheal tube and continue with a general anesthesia.

In the supine position, the risk of puncturing the colon is less than in the prone position, because when the 3-L bag elevates the lumbar fossa, the kidney and the colon are elevated too. In the prone position, the colon is pulled back, increasing this risk of damage.

One of the best technical advantages of the supine position is the ability to perform simultaneously PCNL and URS. With the two endoscopes inside the kidney it is easier to find, fragment, remove, and deliver the stone fragments to be extracted through the Amplatz sheath (see Video 10.1).

Other advantages stem from the ascending direction of the tract. This helps maintain a low intrarenal pressure, making the technique more secure and easier, because the stone fragments are dragged out by the whirlpool of water created in front of the optic, and auxillary instruments are not needed for their extraction (see Video 10.1).

Disadvantages

The supine position has a few disadvantages. In this position there is usually a delay in the filling of the inferior calyces with the contrast, because the inferior renal pole is more elevated than the superior one. This inconvenience can be overcome by positioning the patient, for a few minutes, in an anti-Trendelemburg position.

For percutaneous intervention, distention of the collecting system will be greater in the prone than in the supine position. However, if needed, greater distention in the supine position can be achieved with a simple gauze knot tied around the nephroscope tube, like a plug at the proximal end of the Amplatz sheath. Also, limited filling of the pyelocalyceal system has two advantages: first, it guarantees low intrarenal pressure, and second, in some cases, it reduces the time that it is necessary to work with water [14].

In some thin patients with renal ptosis, the kidney can be hypermobile in the supine position. This inconvenience is overcome by fixing the kidney during tract establishment by means of contralateral abdominal compression.

In some patients with wide hips and thin calyces, it can be more difficult or impossible in the supine position to reach the upper calyx with a rigid nephroscope (see Video 10.1). This difficulty can be solved by performing simultaneously a URS, or by using a flexible nephroscope (see Video 10.1).

Some authors who prefer to make access through the upper calyx have indicated that in the supine position this is more medial and posterior, making access to the upper pole difficult [15]. Nevertheless, others have not been inconvenienced making this upper pole access with their patient in the supine position [16].

Conclusions

Establishing good percutaneous renal access is a crucial step in the PCNL technique. In the supine position, renal access is a simple and safe method which is at reach of any urologist, without the support of any other specialist.

In the supine position, the kidney can be easily explored with ultrasound and punctured with a fluoroscopic C-arm in a fixed position. Biplanar fluoroscopy with a rotating C-arm is no longer essential.

The supine position facilitates the procedure: the urologist can be sitting, with their hands always outside the reach of X-ray. There is also the enormous advantage of being able to combine simultaneously PCNL with a rigid URS, if necessary.

With the supine approach, patients (especially those who are obese) have physiologic intra-abdominal pressures, and therefore less risk of cardiorespiratory complications. In addition, the risk of iatrogenic events is minor, because the position of the patient does not need to change during the intervention.

Our best advice is to try supine positioning, at least once.

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CHAPTER 11

Prone, Lateral, and Flexed: Patient Positioning for Percutaneous Nephrolithotomy

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Introduction

Positioning for percutaneous nephrolithotomy (PCNL) is an important, yet often neglected, aspect of the procedure. Operators invariably become wedded to one position, yet with knowledge and experience of other positions, there is the freedom to choose the most appropriate technique for the case at hand. Since the introduction of percutaneous renal surgery for stone disease by Fernstrom and Johansson in 1976 [1], there has been a proliferation of case series addressing various modifications to patient positioning, including the lateral decubitus position [2–4], modified lateral [5], reverse lithotomy [6], split-leg [7, 8], and supine [9]; however, most of these have not gained widespread acceptance. Today, PCNL is usually performed with the patient in the prone position. We have recently described a prone–flexed modification that confers several advantages over the conventional technique [10].

In this chapter, we review in detail both the conventional prone technique as well as our prone–flexed modification. Additionally, we describe the lateral and our lateral–flexed technique, which we find particularly useful in morbidly obese patients and those with severe kyphoscoliosis. We have also attempted to provide an anatomic explanation for the known complications associated with PCNL, and how attention to patient positioning can mitigate these issues. Finally, the rare complications related to patient positioning are discussed in detail.

Prone and prone–flexed positions

Due to the retroperitoneal location of the kidneys and their proximity to the flank, PCNL is most commonly performed in the prone position with straightforward access to the collecting system. However, when the procedure was being developed in the early 1980s, direct calyceal puncture was not thought to be important, provided that puncture was along the avascular line of Brodel. It has since been recognized that puncture directly into a calyx provides the safest access for stone removal [11, 12]. At present, the majority of PCNLs are performed with the patient prone and access is obtained through a posterior or posterolateral calyx. This position confers numerous advantages, with the main disadvantages being the time required for patient repositioning and anesthetic concerns in the morbidly obese (Table 11.1). We have previously shown that the prone–flexed position, a simple modification to conventional prone positioning, has several additional advantages [10] and can be implemented on most operating room (OR) tables.

Percutaneous lithotomy in the prone and prone–flexed positions (see Video 11.1)

Retrograde pyelogram and choice of calyx

To perform fluoroscopically-guided access, a high-quality retrograde pyelogram is essential. Consequently, we begin all procedures with the patient positioned supine. Once the patient has been intubated under

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Table 11.1 Options for prone patient positioning.

	Technique	Advantages	Disadvantages
Prone	Patient is prone with a padded role under the thorax to facilitate ventilation	Large field with wide choice of calyces for access Easy end-on access to the posterior calyces Easiest access to upper pole Wide space for instrument manipulation Renal pelvis is dependent with easier access to mobile stones Optimal position for fluoroscopically guided access (“bullseye” or “triangulation”) Minimal interference from the OR table	Patient repositioning prolongs OR time Difficult in obese patients Risk of respiratory or cardiovascular compromise Theoretical risk of ocular complications
Prone-flexed	Patient is prone, with a padded role under the thorax to facilitate ventilation Flexed at the waist 30–40° Knees are flexed 15°	Similar advantages to prone position Further increased working space Flattened flank decreases instrument conflicts with buttock May convert supra-11th to supra-12th or supra-12th to infracostal access	Similar disadvantages to prone position Extra padding needed due to head-down position May increase airway pressures
Prone split-leg	Patient prone, with the genitalia at the bottom of the OR table Legs on padded adaptors and abducted up to 45°	Similar advantages to prone position May perform ureteroscopy without patient repositioning or fear of contaminating instruments	Similar disadvantages to prone position Patient is further down the OR table, away from the anesthesiologist

general anesthesia, flexible cystoscopy is performed. In men, this is performed with the patient supine, while the frog-leg position is useful in women. A 5F Flextip (Cook Medical) ureteral catheter with a terminal side hole, which facilitates aspiration, is passed into the collecting system. Urine is completely aspirated and replaced with radiographic contrast to identify all calyces. Urine is less dense than contrast. As a result, any urine within the collecting system will tend to collect at the highest point within the kidney. This property can be helpful to the surgeon when distinguishing anterior and posterior calyces. In the supine position, posterior calyces are identified by the presence of denser contrast within them, while anterior calyces appear paler due to the mixture of contrast with urine. In contrast, when the patient is repositioned prone, posterior calyces will appear paler. If too much pure urine without contrast is present, these calyces may be poorly visualized or even invisible.

A C-arm image intensifier is used to examine the anatomy of the collecting system and the position of all stones. Four fluoroscopic images are captured: a scout image to identify all calculi, an anteroposterior, and two obliques. These images help create a mental three-dimensional (3D) picture of the calyceal anatomy, and can be referred to during the procedure. In the anterolateral view, the posterior calyces are viewed from the side and appear longer, whereas in the anteromedial view, they are seen through the central axis of the kidney and are viewed end-on, appearing shorter (Figure 11.1).

A ureteral occlusion balloon is then inserted over a guidewire, positioned at the uteropelvic junction (UPJ), and secured externally to a Foley catheter. A three-way valve is attached and connected to a 10 mL syringe and intravenous tubing leading to a bottle of contrast. This allows aspiration and infusion of additional contrast as needed during the case. Using an occlusion balloon has several benefits. First, the balloon prevents stone fragments from falling into the ureter. Second, the constant pressure of contrast in the renal collecting system ensures a persistent pyelogram, facilitating calyx identification when the patient is repositioned prone. Third, flow of contrast under gravity distends the collecting system, providing a larger target for access. Fourth, free return of contrast out through the needle allows the surgeon to rapidly confirm successful puncture of the chosen calyx. Finally, the occlusion balloon can act as a safety device, providing control of the ureter and UPJ throughout the procedure.

Renal puncture and dilation of the tract

With a Foley catheter *in situ* and the ureteral occlusion balloon secured externally, we reposition the patient

Image not available in the electronic edition

Figure 11.1 3D model of the lower pole renal collecting system of the right kidney with the patient in supine position. The posterior calyx is dependent, filling with dense contrast. Anterior calyces are paler due to the mixture of contrast with less dense urine. (A) With the C-arm rotated 30° toward the left side of the patient, the posterior calyx is viewed end-on and appears shorter. (B) Anteroposterior view. (C) With the C-arm rotated 30° toward the right side of the patient, the posterior calyx is viewed from the side and appears longer (reproduced from Ray *et al*. [10] with permission.

prone with the assistance of additional staff members. Generous padding is placed under the knees, feet, and chest to prevent pressure injury and to facilitate ventilation (Figure 11.2). Our anesthesiologists use generous padding of the eyes to prevent corneal abrasions and have various head supports at the ready with cut-out holes for the endotracheal tube. We have found that there is no one support that is universally appropriate for all patients, so several options are available at all times. To prevent brachial plexus injury, the shoulders should be situated below the chest and are both externally rotated at the shoulder and flexed at the elbow. Again, generous padding is utilized. Finally, a safety strap is place across the buttocks.

In the prone position, the natural, anterior lordosis of the spine is exaggerated. This complicates access by compressing the working space and leads to instrument conflicts with the buttocks. To avoid this, the table can be flexed 30–40° to open the space between the 12th rib and the posterior iliac crest (Figure 11.3). Flexion of the hips not only increases the working space on the patient's flank, but also may rotate the ribs cephalad, further increasing the working space and possibly converting a supracostal to an infracostal access.

Skin preparation is up to the surgeon's preference. In one recent multicentered randomized study examining the issue of surgical site infections following clean-contaminated surgery, it was found that skin preparation with chlorhexidine–alcohol was superior to povidone–iodine in the perioperative period [13]. We perform wide skin preparation from above the 10th rib to the buttocks and from the spinous process in the patient's midline, laterally to the mid-axillary line. Due to the copious amount of irrigation necessary for PCNL, we use an adhesive neurosurgical drape with a drainage pouch connected to suction to direct fluid away from the patient. Only normal saline irrigation is used unless electrocautery is required, when it is changed to a nonelectrolyte solution such as is used for transurethral prostatectomy. To prevent hypothermia, all irrigation fluid is heated to 42°C in a warming cabinet.

"Bullseye" technique

The C-arm is draped and used to identify the previously chosen calyx. Due to the change to the prone position, the posterior calyces are now less dense as the heavier contrast flows anteriorly (Figure 11.4). We favor a conventional "bullseye" technique for performing renal puncture in the prone position; however, a "triangulation" technique can also be used (described below). Prone and prone–flexed positioning allows maximal

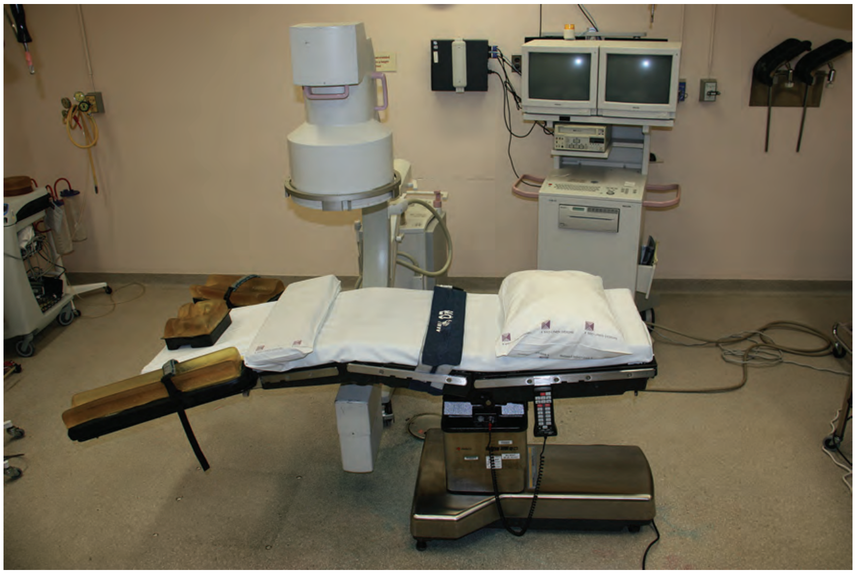

Figure 11.2 Configuration of OR table with padding and C-arm.

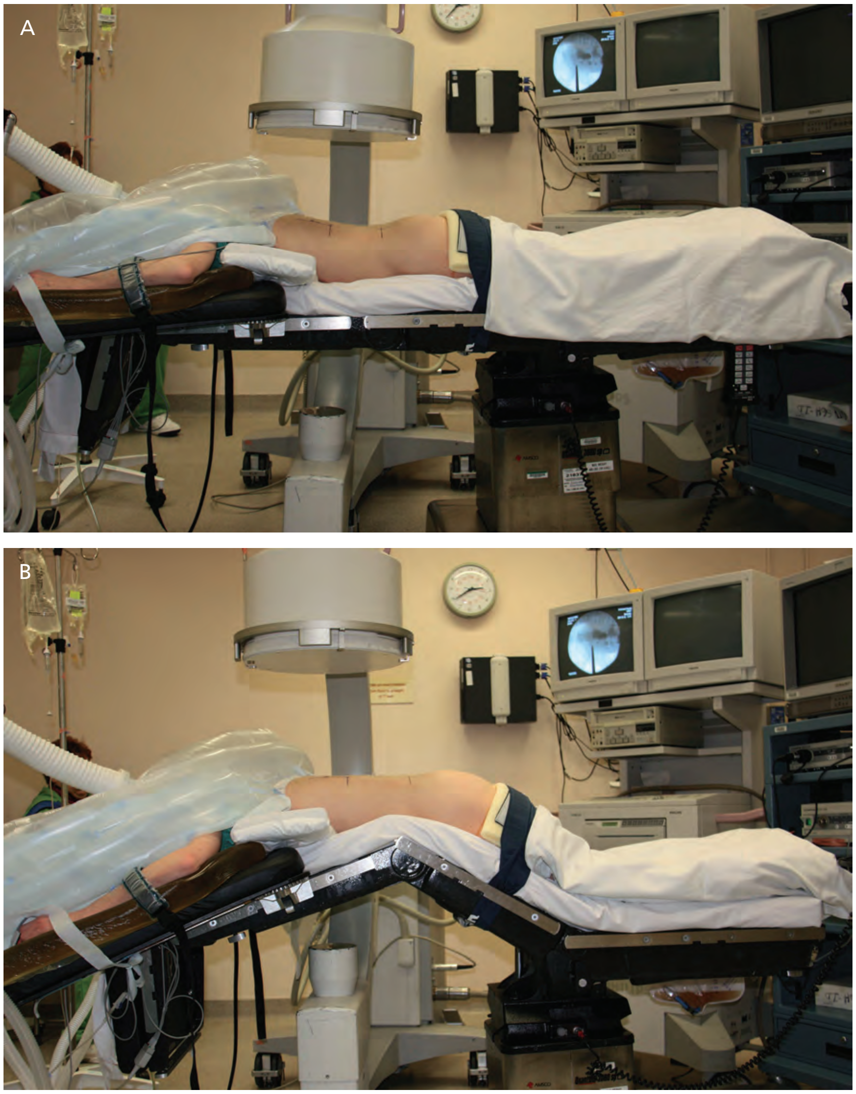

Figure 11.3 (A) Prone and (B) prone-flexed patient positions. A padded support is placed under the patient's chest to improve respiration. With the OR table flexed 30–40°, the patient's flank is flattened and there is increased area available for puncture. Note also that prone–flexed positioning decreases obstruction from the buttocks with lower pole access.

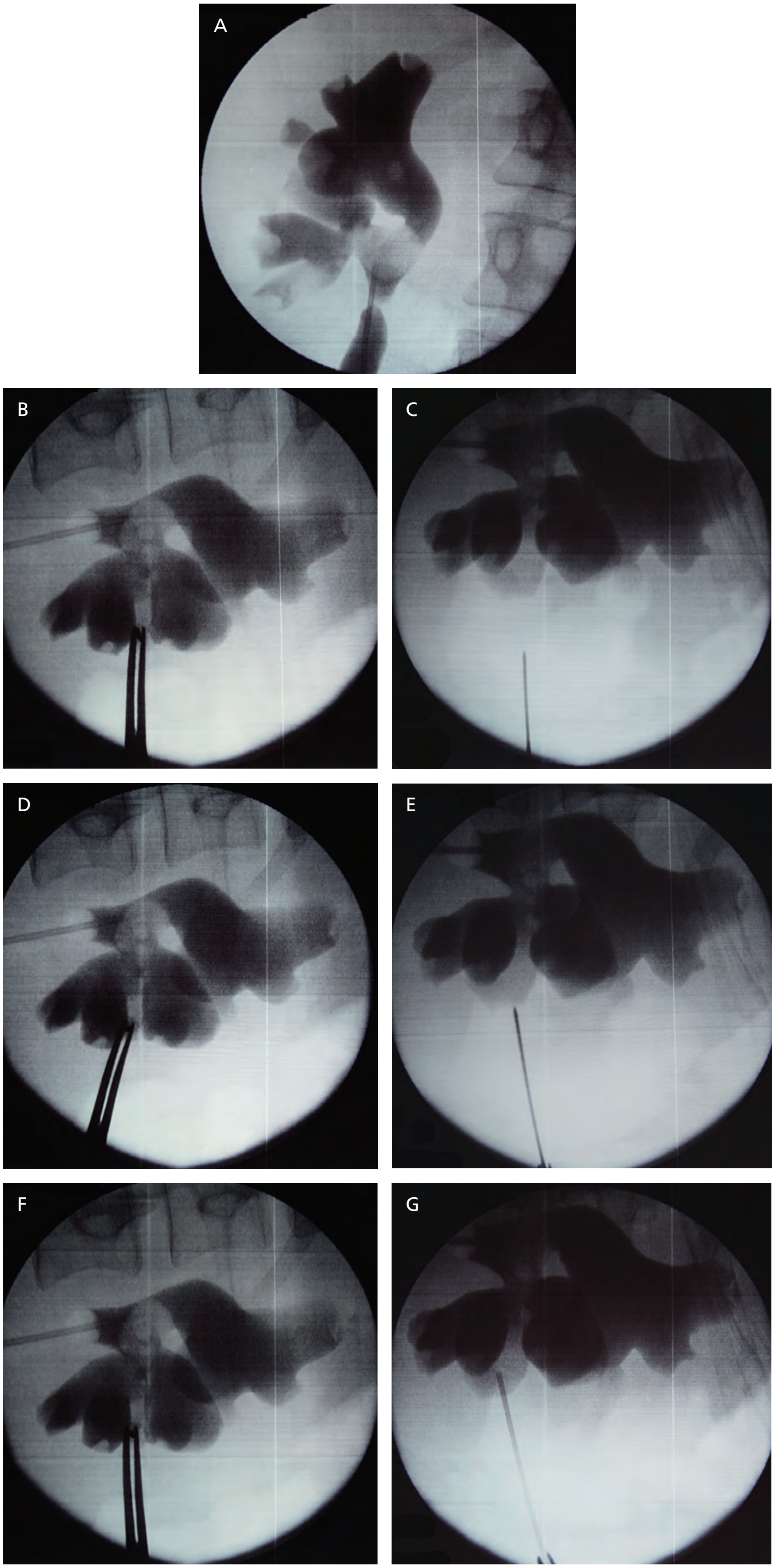

Figure 11.4 "Bullseye" technique. (A) Anteroposterior (AP) view with the patient in the supine position. All subsequent images are with the patient in the prone–flexed position. (B) AP view with the forceps holding the needle and aimed at the chosen posterior calyx. (C) 30° oblique view demonstrating the depth required for puncture. (D) AP "bullseye" view. (E) 30° oblique view. (F) AP view. (G) Oblique view with the chosen calyx successfully puncture by the needle.

excursion of the C-arm around the OR table, giving the widest possible unobstructed imaging windows. In the prone position, the posterior calyces move in the opposite direction to the image intensifier of the C-arm (Figure 11.4). With the C-arm rotated 30° from the vertical, towards the operator, the posterior calyces move away, and shorten. In this position, the calyx of choice is viewed end-on. We use an 18G Trocar needle to puncture the calyx in the center of the papilla. This needle lacks a beveled edge and as such, resists deflection away from the axis of puncture. The needle is inserted and advanced along the line of the X-ray beam. To assess the depth of the needle, the C-arm is periodically rotated away from the operator (Figure 11.4). To minimize radiation exposure to the surgeon's hands, the needle can be held in a long Kelly forceps, aligned with the calyx under fluoroscopy, and advanced during expiration without fluoroscopy. Once the calyx is entered, and a free flow of contrast obtained, an Amplatz extra-stiff or super-stiff guidewire is passed down the needle into the collecting system. Due to the presence of the occlusion balloon, we do not attempt to pass the guidewire down the ureter, although this may occur. A small depth gauge ring on the needle is adjusted to skin level to mark the depth between the skin and the collecting system. Knowledge of this measurement reduces radiation exposure during insertion of the fascial dilators and nephrostomy tract dilating balloon. Initially, thin fascial dilators are used to dilate the tract to a short 10F, and then a safety guidewire can be inserted using a 10F dual-lumen catheter. The tract is then further dilated to 30F with a nephrostomy tract dilating balloon over which an Amplatz sheath with a 30F inner diameter is passed. Although different methods of tract dilation exist, including balloons, Amplatz serial dilators, and the Alken telescopic dilator among others, we favor balloon dilation. We have found this to be both quick and atraumatic, although this comes at increased cost.

Adjuncts to assist with patient positioning

The prone–flexed modification can add several advantages to the operating surgeon without any impediment to C-arm movement. Adopting this position on an OR table without a flex-option is still possible through the use of bolsters. The "Montreal mattress" is a preshaped surgical bolster that can be used as an adjunct for the support of prone patients [14]. The advantage of this device is the central cavity which allows for free movement of the abdomen. Theoretically, this should lessen respiratory compromise and minimize cardiovascular effects such as inferior vena cava (IVC) obstruction. Another option is the radiolucent Wilson frame, an adjunct used by spinal surgeons to mimic the prone–flexed position on a standard OR table. Its advantages include the ability to control the degree of flexion required as well as to use adjustable contour pads that allow for free excursion of the abdomen, preventing respiratory compromise. The main limitation to its use is the reduction in depth, preventing C-arm movement, instrument manipulation, with fluoroscopic guidance.

Advantages and disadvantages of the prone position

As mentioned, the majority of PCNLs are still carried out with the patient in the prone position, with prior retrograde placement of a ureteral catheter or occlusion balloon under fluoroscopic control. This initial procedure can be performed with the patient either supine or prone. If performed while the patient is supine, it is necessary to position and drape the patient twice, prolonging OR time [15, 16]. By commencing the procedure with the patient in the prone position immediately following induction of general anesthesia, the patient will still require repositioning, but is only draped once [17]. A split-leg modification can facilitate access to the external genitalia, for simultaneous antegrade and retrograde approaches [7, 8]. In the prone position it may be difficult to access the anteriorly displaced ureteric orifices for the retrograde study, but with practice this can become routine. Additionally, if the procedure is started prone, identification of the posterior calyces, especially in obstructed systems, may be difficult, or impossible, as the presence of pure urine within the collecting system may float on top of the radiographic contrast and render them invisible. For this reason, it is our preference to begin the procedure with the patient supine.

Prone positioning for PCNL allows access to the entire flank, with a wide choice of access sites, especially when multiple accesses are required. Although still possible in the supine position, upper pole access is significantly easier when the patient is prone. An upper pole puncture has many advantages, including the ability to work down the renal axis, with minimal torque, as the more mobile lower pole rotates to align with the nephroscope. This reduces the chance of renal parenchymal shear and bleeding. Selection of an upper pole calyx is indicated in obese patients, as the upper pole is closer to the posterior abdominal wall than the lower pole. It is also indicated in patients with staghorn calculi, or stones in a horseshoe kidney, and facilitates access to multiple lower pole calyces, with a single tract. In contrast, from the lower pole, visualization of the upper calyces with a rigid nephroscope is rarely possible. Finally, dilation into the upper pole is easier, due to more adherent attachments to Gerota's fascia limiting renal mobility, whereas the more mobile lower pole may move away from the operator during dilation and kink the guidewire. Despite these advantages, many authors still prefer a lower pole puncture with the reassurance that this approach will avoid thoracic complications.

The prone–flexed modification that we describe provides several additional advantages over the traditional technique. First, and most obviously, the working space is further increased. In addition, we have shown that when in this position, the kidneys are displaced inferiorly in the retroperitoneum. This effect is most pronounced with the left kidney, which is lower than the right kidney in greater than 90% of cases. Also, due to this modification, a supra-11th rib access may be converted to a supra-12th rib, or a supra-12th to an infracostal access. Finally, the flank is significantly flattened, eliminating interference from the buttock during rigid nephroscopy through a lower pole tract [10].

Lateral and lateral–flexed positions

Although the prone–flexed position for PCNL can be used for the obese patient, the lateral position has multiple advantages in these patients, and is sometimes the only feasible position for the morbidly obese patient with a body mass index in excess of 50 kg/m^2 who cannot be ventilated prone. This position allows the protuberant abdomen and pannus to fall laterally, taking the weight off the anterior abdominal wall as occurs when the patient is supine (Figure 11.5). This maximizes diaphragmatic excursion and facilitates general anesthesia. The pannus can also be supported separately if required.

The lateral–flexed position is familiar to any urologist who performs open and laparoscopic renal surgery. This position significantly widens the space between the 12th

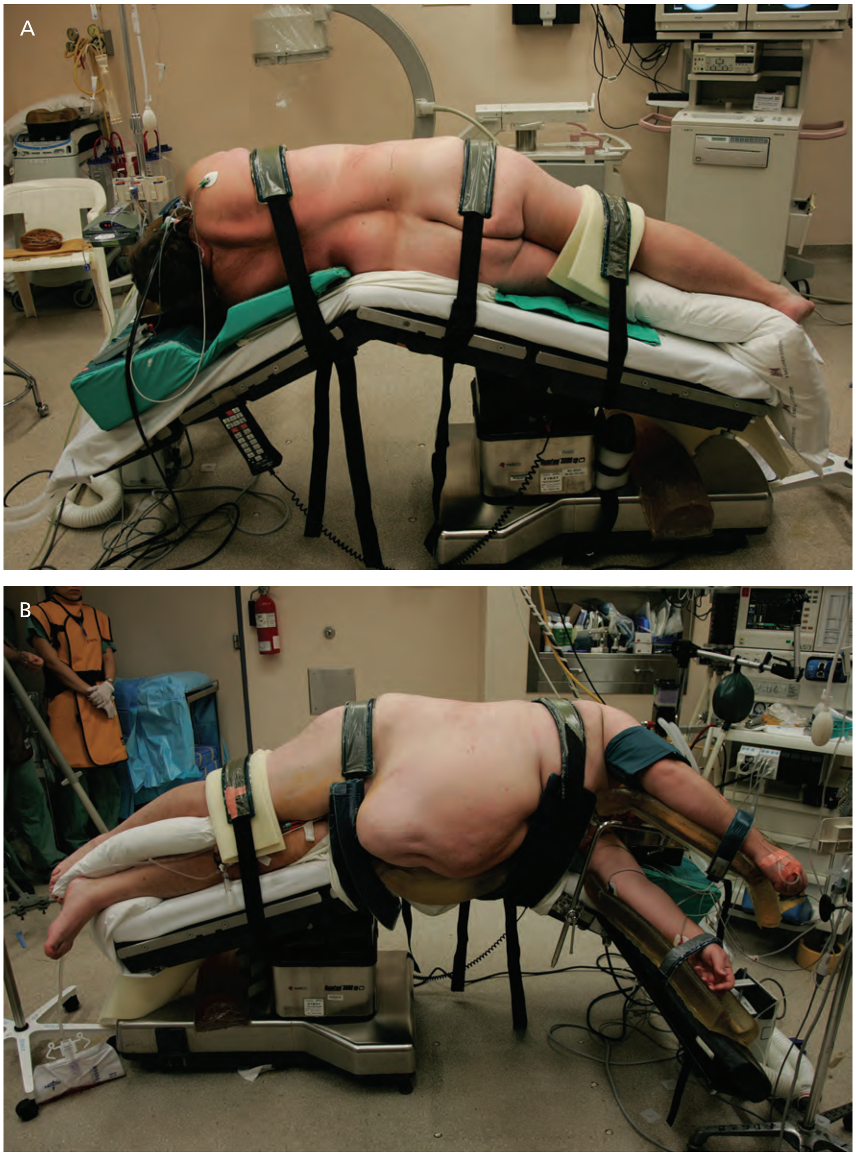

Figure 11.5 Lateral-flexed patient position. (A) Posterior view. A wedge with a groove for the dependent arm is placed under the patient's torso. (B) Anterior view. Both arms are supported and flexed slightly at the elbow. Generous padding is used to prevent injury. Note that the pannus falls away from the patient, preventing respiratory compromise.

rib and the iliac crest, flattening the folds of adipose tissue and facilitating percutaneous access (Figure 11.6). The increased distance between the 12th rib and iliac crest, produced by this flexion, is even more pronounced than the increase produced by flexion with the patient prone. Also, in this position, the relative lack of adipose tissue over the costovertebral angel is frequently surprising in these morbidly obese patients and, provided the upper pole calyx is chosen for access, it is frequently possible to use a standard length Amplatz sheath and nephroscope.

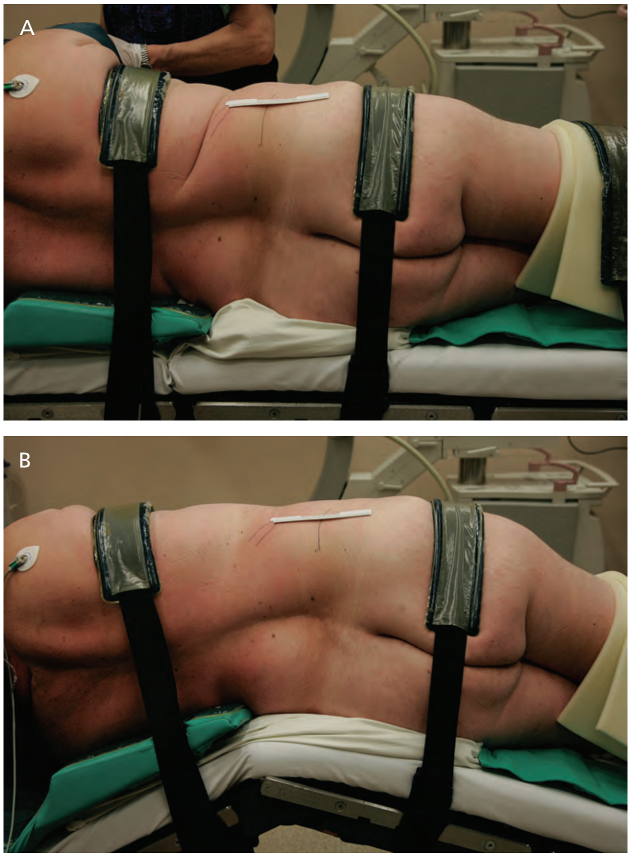

Figure 11.6 (A) Lateral and (B) lateral-flexed patient positions. As with prone-flexed positioning, when the OR table is flexed 30–40°, the patient's flank is flattened and there is increased area available for puncture.

One disadvantage to flank positioning is that percutaneous access usually requires either ultrasound guidance or use of "triangulation" using the C-arm image intensifier, as opposed to the "bullseye" technique. This is partly because of the restricted arc of rotation of most C-arms, but also because the metal side rails of most radiolucent tables prevent adequate visualization of the collecting system when the C-arm is rotated to an exaggerated position. Advantages of the lateral and lateral–flexed positions are outlined in Table 11.2.

Percutaneous nephrolithotomy in the lateral and lateral–flexed positions (see Video 11.2)

As with prone or prone–flexed PCNL, the procedure begins with a retrograde pyelogram and insertion of a ureteral occlusion balloon. This is performed with the patient supine in order to choose the most appropriate calyx, as described earlier (Figure 11.7).

In the lateral–flexed position the arms and legs are positioned as for open or laparoscopic renal surgery, and the patient is secured to the table with padded straps or tape over the upper chest and pelvis (Figure 11.5). An axillary roll or padded wedge with a groove to accommodate the dependent arm must be placed to adequately support the chest and prevent positioning-related injury. Extra padding must also be placed under the dependent knee and ankle to prevent pressure-related complications.

The concept of triangulation is illustrated in Figures 11.8 and 11.9. With the C-arm in the anteroposterior configuration, it is possible to determine the

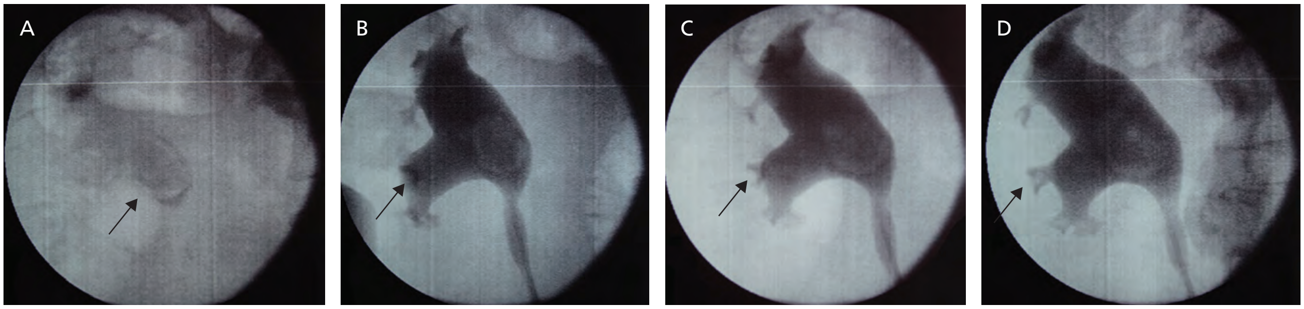

Figure 11.7 Choosing a posterior calyx (arrow) in the lower pole of the right kidney, for the case demonstrated in Figure 11.10. The patient is in the supine position and the posterior calyces appear darker. (A) Renal pelvic stone. (B) Oblique view with C-arm rotated 30° toward the left side of the patient, making the posterior calyx appear shorter. (C) Anteroposterior view. (D) Oblique view with the C-arm rotated 30° toward the right side of the patient, making the posterior calyx appear longer.

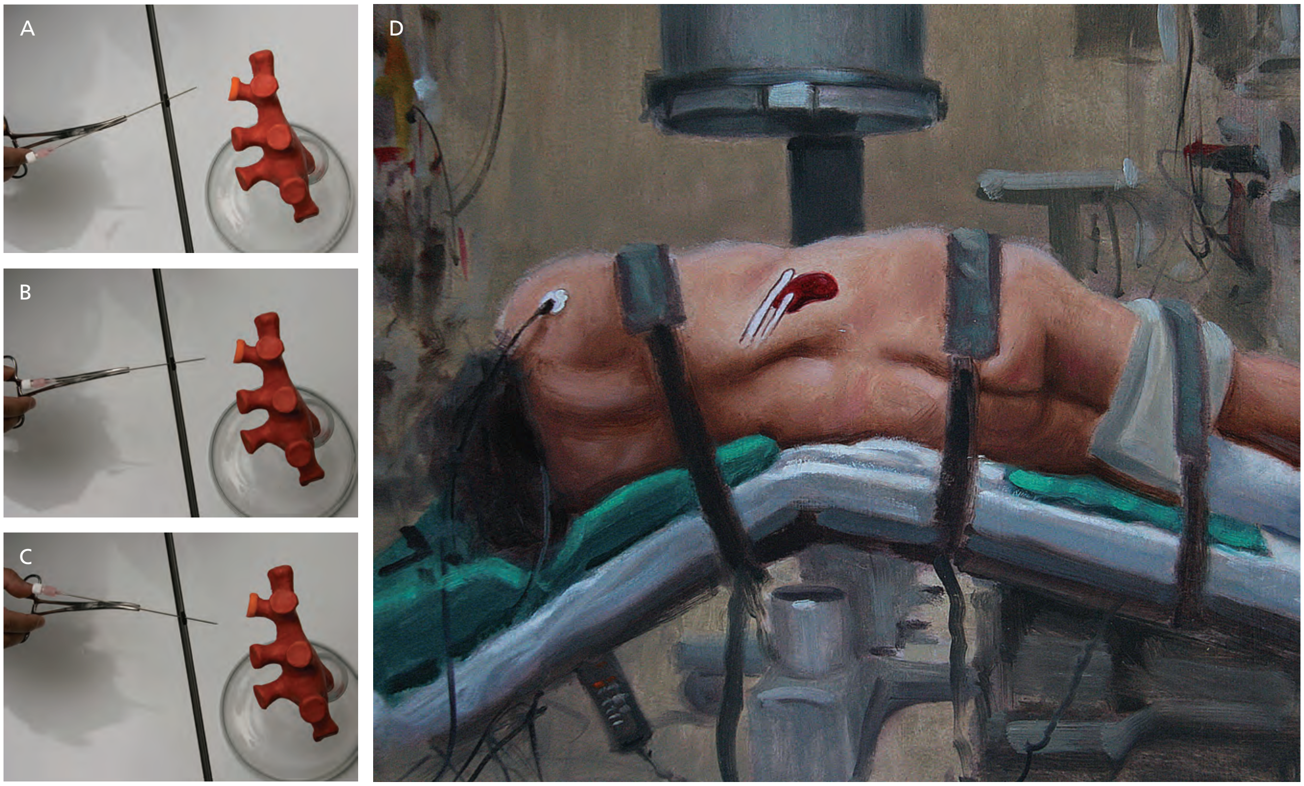

Figure 11.8 Anteroposterior views with the patient in the lateral-flexed position. In this demonstration, the target is an upper pole, posterior calyx, viewed from directly above. The chosen calyx is seen from the side, facing posteriorly. (A) Needle is aiming too cephalad to the target calyx. (B) Needle will have direct entry into the papilla of the desired calyx. (C) Needle is aiming too caudal to the target. (D) Illustration depicting the position of the C-arm necessary to obtain this view.

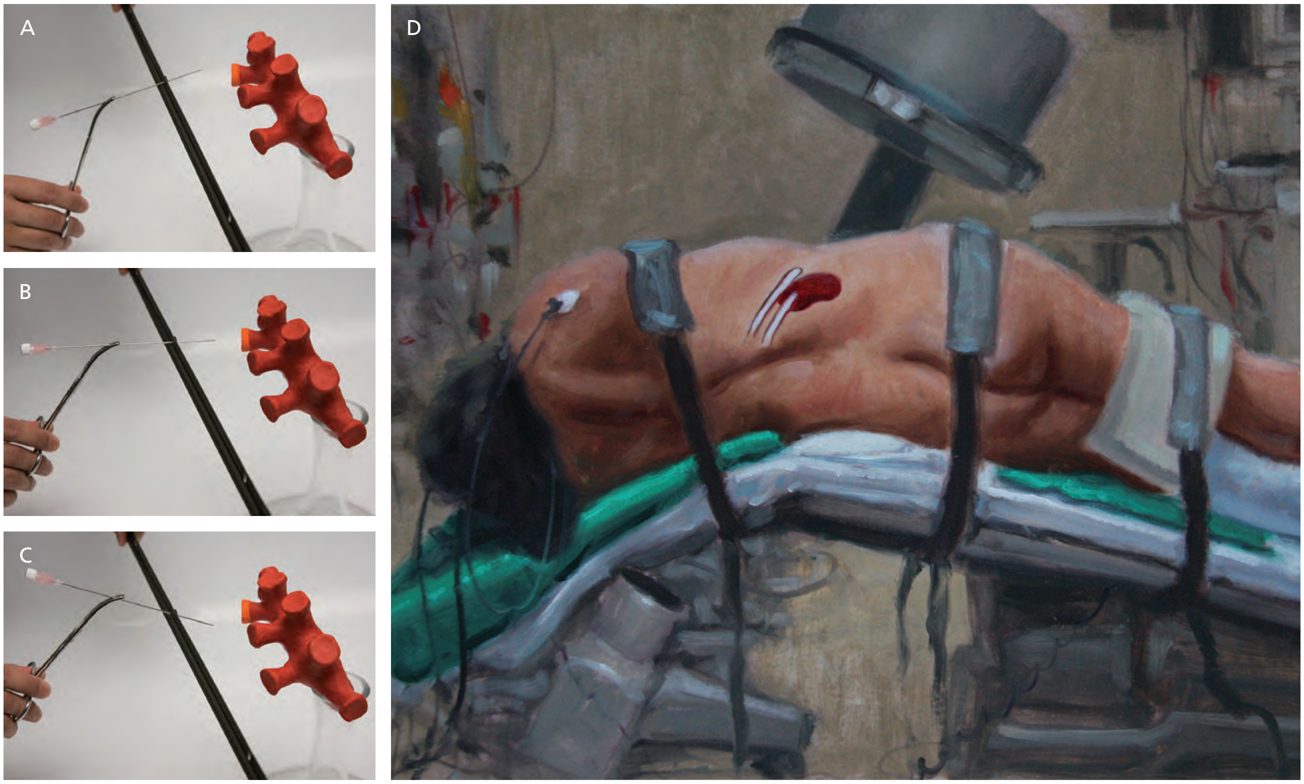

Figure 11.9 Oblique views with the patient in the lateral–flexed position. With the C-arm offset approximately 30° towards the feet, the targeted posterior, upper pole calyx is identified. (A) Needle is aiming too far anterior to the target calyx. (B) Needle will have direct entry into the papilla of the desired calyx. (C) Needle is aiming too far posterior to the target. (D) Illustration depicting the position of the C-arm necessary to obtain this view.

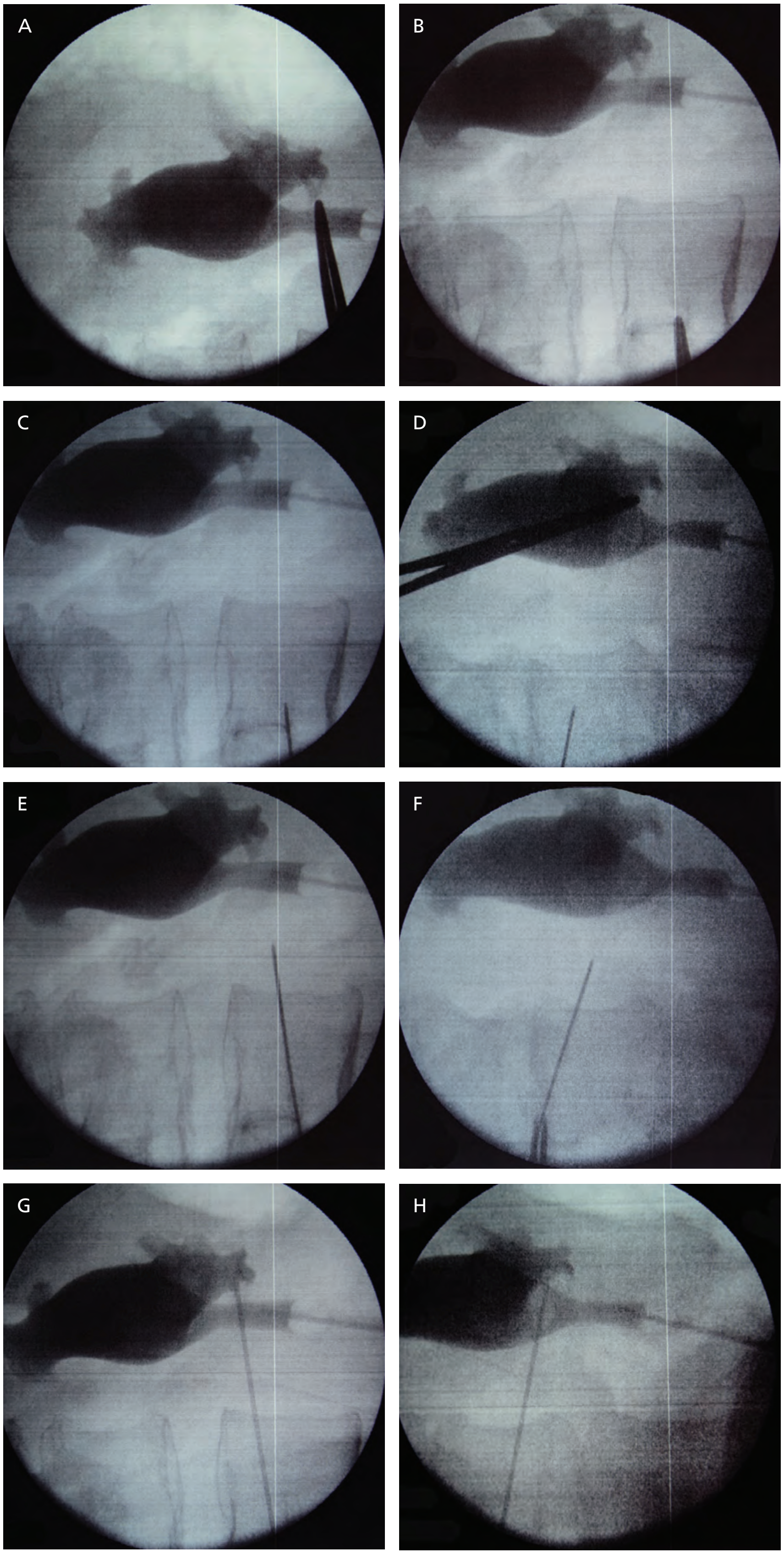

Figure 11.10 Triangulation technique with an obese patient in the lateral-flexed position. (A) Forceps pointing to chosen posterior calyx viewed in anteroposterior (AP) direction. (B) Point of entry chosen with forceps marking point lateral to the paraspinal muscles in line with the targeted calyx. (C) AP view with the needle along the chosen path. (D) Oblique view with the needle pointing to the chosen calyx. (E) AP view with the needle approaching the calyx. (F) Oblique view with the needle on target, approaching the calyx. (G) AP view with the needle in the chosen calyx. (H) Oblique view with the needle in the chosen calyx.

Table 11.2 Options for lateral patient positioning.

	Technique	Advantages	Disadvantages
Lateral	Patient in lateral decubitus with no break in the OR table	Familiar to urologists who perform open renal surgery Compared with prone, easier patient repositioning from supine Easiest identification of the posterior calyces Useful in morbid obesity or severe kyphoscoliosis Least effect on cardiac and respiratory function Renal pelvis is dependent with easier access to mobile stones More ergonomic for the surgeon than prone position May perform nephroscopy and ureteroscopy simultaneously	Patient repositioning is required Fluoroscopy is technically limited necessitating "triangulation" or ultrasound-guided access
Lateral-flexed	Patient in lateral decubitus with 30–40° break in the OR table	Similar advantages to lateral position Significantly increased working space Reduces flank fat in morbidly obese patients May elevate the lower ribs, reducing the need for supracostal access	Similar disadvantages to lateral position
Modified lateral "Barts technique"	Patient in lithotomy with ipsilateral pelvis elevated 45° Shoulders rotated to be perpendicular to the OR table Ipsilateral leg is flexed and adducted, contralateral leg is fully abducted	May perform nephroscopy and ureteroscopy without patient repositioning Less cardiovascular and respiratory effects than prone Improved access to flank compared to supine	Requires significant patient mobility Not suitable for patients with musculoskeletal deformities Fluoroscopy is technically limited, as with lateral

cephalad–caudal axis for puncture. Oblique views are similarly used to determine the anteroposterior direction of puncture. In this view, directing the needle laterally toward the anteroaxillary line will target the anterior surface of the kidney, while directing the needle toward the spine will aim it toward the posterior surface.

With the patient in the lateral position and the C-arm image intensifier placed on the abdominal side of the patient, the pelvicalyceal system is initially viewed in the anteroposterior position. The previously chosen calyx can be identified facing posteriorly towards the operator (Figure 11.10). The line of access can then be chosen. This can be the shortest distance, at right angles to the back, or can work along the axis of the kidney, angling up into a lower pole calyx or angled down into an upper calyx. The actual puncture is made two finger breadths lateral to the edge of the paraspinal muscles. If necessary, the site that was initially chosen may be adjusted either cephalad or caudally if a rib is in the line of the needle tract. The needle is then advanced with fluoroscopic monitoring. With the C-arm vertical or rotated 10–20° towards the X-ray machine, to lengthen the calyx, the needle is angled in a caudal or cranial direction to point directly at the calyx (Figure 11.10). Holding this angle steady, the C-arm is swung with the intensifier towards the foot of the table and the anteroposterior direction of the needle adjusted to again point directly at the chosen calyx. The needle is then advanced along this line, checking both angles at regular intervals until the calyx is punctured. The stylette is removed and contrast should flow freely from the needle.

Special situations

Morbid obesity

PCNL in the morbidly obese patient with a BMI greater than 40 kg/m^2 poses a challenge for both the operating surgeon and the anesthesiologist. From a surgical perspective, there are several aspects that must be considered. First, achieving satisfactory X-ray penetration can be problematic with older fluoroscopic units, making targeting difficult. Second, anatomic landmarks are also obscured and can make tract placement difficult. This can be especially problematic for upper pole punctures. Third, the depth of the tract is significantly increased and often requires extra-long instruments, including a sheath and rigid endoscopes. Surprisingly, several authors have independently demonstrated that both stone-free rates and perioperative complications appear to be unaffected when PCNL outcomes are stratified by BMI [18–22]. This was despite the increased complexity of these cases and the poor fluoroscopic image quality obtained when using the C-arm to search for small residual fragments.

In terms of patient positioning, the lateral–flexed position seems ideally suited for this clinical situation, with the benefits explained in detail above (Table 11.2). Other authors have similarly used lateral positioning to overcome these difficulties. Kerbl *et al*. described in detail the use of lateral positioning to successfully treat two patients with a BMI greater than 50 kg/m^2. In these patients, it was noted that the supine position could not be tolerated due to respiratory difficulties [2]. Gofrit *et al*. echoed these concerns and similarly adopt the lateral decubitus position in patients with a BMI greater than 40 kg/m^2 [3]. In contrast, conventional prone positioning has been used by several authors for the morbidly obese, including patients with a BMI well over 50 kg/m^2 [20, 21]. The prone position may still be well-tolerated even at extremes of BMI and may be useful when the weight of the patient is greater than the tolerance of the OR table, requiring the use of two tables in close proximity. Wu *et al*. described a technique of awake endotracheal intubation and prone self-positioning in a patient with a BMI of 51 kg/m^2 [23]. In a large series, El-Assmy *et al*. favored supine positioning for morbidly obese patients, but conceded that prone positioning was necessary in some cases]. Finally, Curtis *et al*. described using the prone position in a patient with a BMI of 55.5 kg/m^2. Their technique was to use a larger skin incision to expose the fascia prior to performing puncture [24]. This technique has the potential for avoiding the need for an extra-long working sheath, but can only be used with the patient in the prone or lateral decubitus positions.

Kyphoscoliosis/musculoskeletal abnormalities

The treatment of patients with severe musculoskeletal abnormalities poses a particular challenge to the surgeon, and PCNL is no exception (Figure 11.11). In these

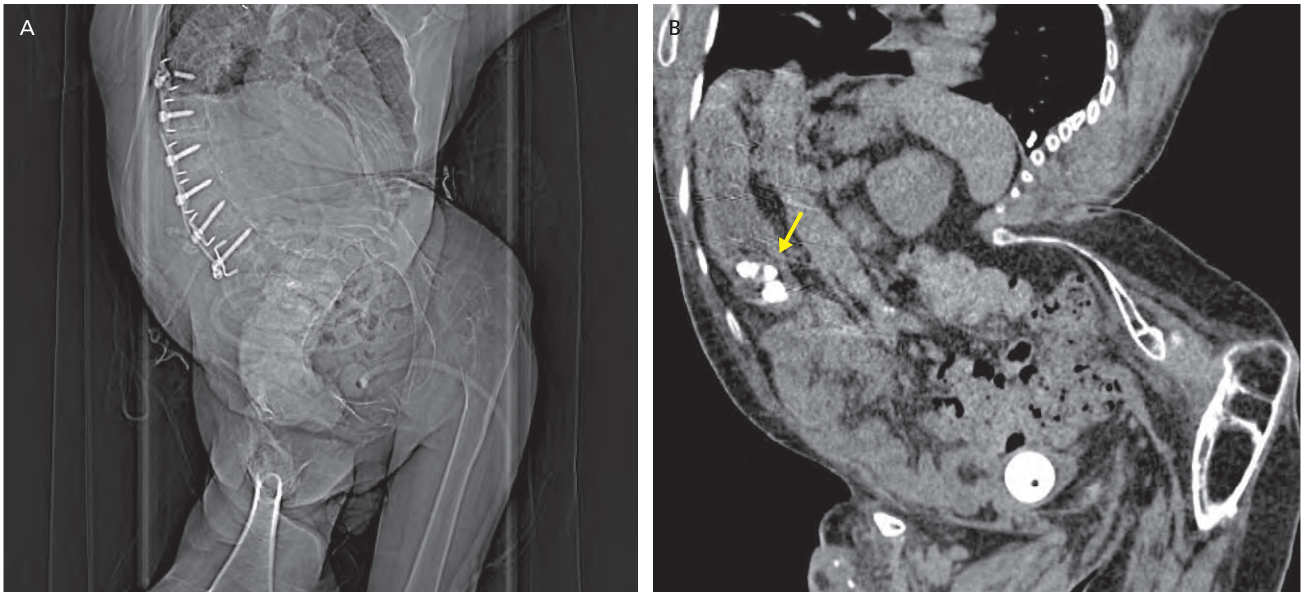

Figure 11.11 (A, B) A patient with severe kyphoscoliosis and a neurogenic bladder. The indication for percutaneous nephrolithotomy was an infected partial staghorn calculus of the right kidney (arrow). Contrast incidentally fills the foley catheter balloon in B. The patient could not tolerate either prone or supine positioning, thus lateral decubitus positioning was used without flexion of the OR table.

patients, the loss of bony landmarks, distorted position of abdominal organs in relation to the target kidney, and difficulties with imaging secondary to X-ray penetration and interference from orthopedic hardware make PCNL difficult. To date, there is limited published data describing PCNL in the patient with severe kyphoscoliosis. Gofrit *et al*. described a single case of severe kyphosis preventing prone positioning. In this case, the lateral decubitus position provided good access to the flank. However, an upper pole nephrostomy had been placed in the radiology suite in advance of the procedure and was used to access the renal pelvic and lower pole calculi [3]. Matlaga *et al*. described a technique for computed tomography (CT)-guided access and included six patients with scoliosis in their dataset [25]. Anecdotally, we have used both prone and lateral positions for this population. No position is universally appropriate and adaptability is of paramount importance. Often, when the fluoroscopic window is limited, access must be secured by the interventional radiologist or trained urologist using ultrasound guidance. Additionally, such patients require additional padding as they can be prone to both pressure ulcers and nerve injuries.

Renal anomalies

Urolithiasis in horseshoe kidneys (HSKs) is common, occurring with a reported incidence of 20–60% [26]. The accompanying rotational anomaly results in calyces that are oriented more posteriorly and a renal pelvis that is more anterior than in “normal” kidneys [27]. The lower pole is also oriented more medially and is fixed in the midline by the isthmus that connects it to the contralateral kidney. As a result, upper pole access is preferred as this provides the least angulation looking down the axis of the kidney, and minimizes torque when manipulating stones located in the renal pelvis and lower pole calyces. When puncture is performed through the lower pole calyces, the tract is significantly longer and at a right angle to the renal axis. Consequently, accessing the upper pole may be difficult or even impossible with a rigid endoscope. Finally, the puncture site through the skin is often located more medially, when accessing the mid or lower calyces, and this can result in injuries to the segmental arteries. Together, all these factors favor PCNL in either the prone or lateral positions [28]. Indeed, supine PCNL in the patient with HSK has not been described and is likely contraindicated in this patient population.

Surgical tables for select positions

There are numerous surgical tables available for both general and endourologic procedures, and as such, a review of each is beyond the scope of this chapter. However, the ideal table will be adaptable to the needs of both the patient and surgeon. For PCNL, an OR table should have a radiolucent, carbon-fiber top with narrow side rails for straps or arm rests. To allow the maximum number of positioning options, the table should also have the ability to flex and raise the legs, and have attachments for leg stirrups for the lithotomy position. It should also be possible to slide the table top towards the head or feet. From a technical perspective, the table should also be offset with a narrow base, allowing wide movement of the C-arm and a large imaging window.

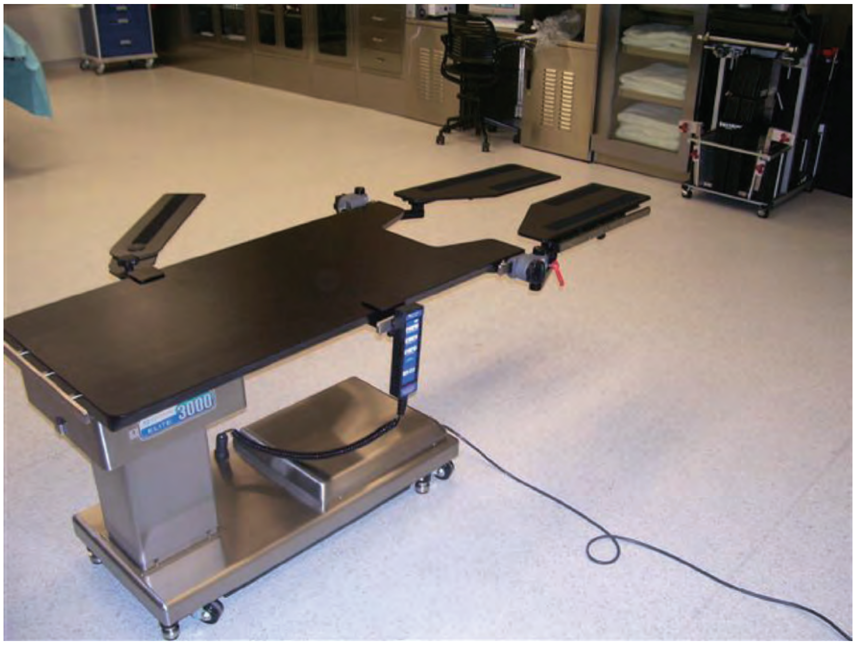

Figure 11.12 Modified Skytron carbon-fiber OR table with stirrups. Note the lack of side rails and large, unobstructed imaging window. This model does not flex. To place the patient in the flexed position, appropriate bolsters and positioning devices are required.

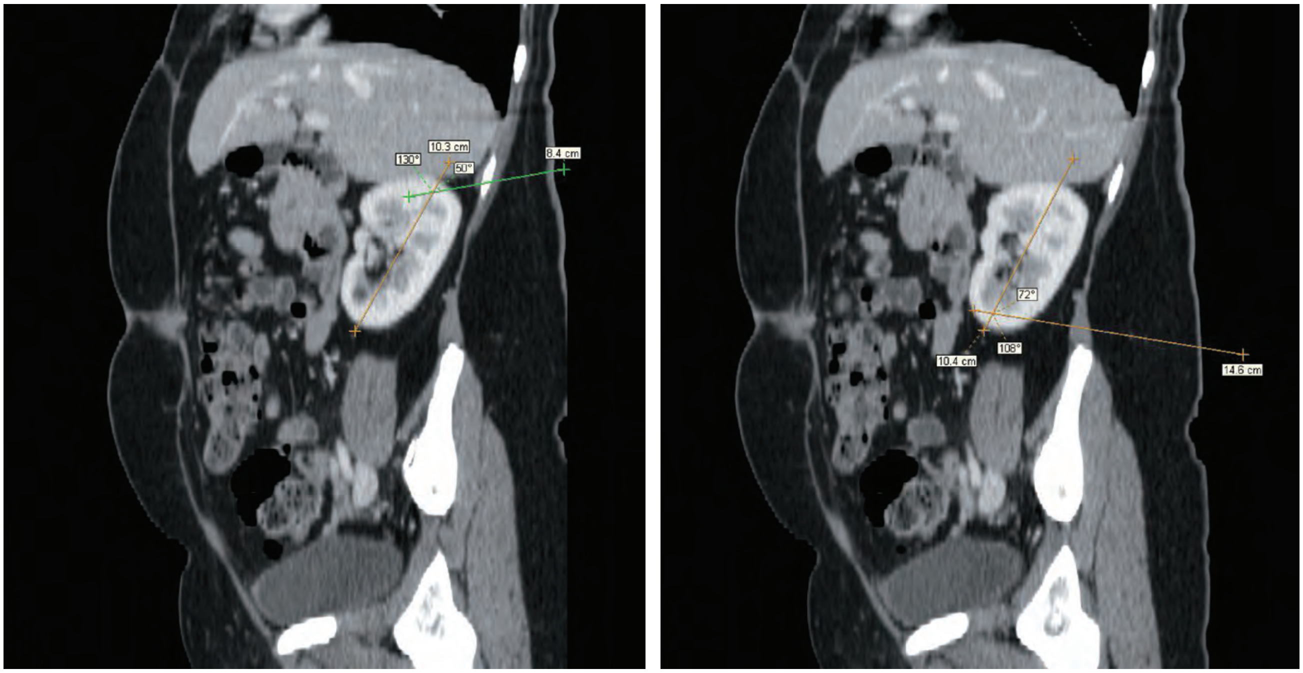

Figure 11.13 Sagittal CT reconstruction of the right kidney demonstrating puncture of upper and lower pole posterior calyces. Upper pole punctures are shorter and more in-line with the uteroposterior junction and renal pelvis, whereas lower pole punctures are longer and have more acute angles, leading to more torque and renal shear.

Finally, it should be possible to accommodate patients up to 600 lb.

The carbon-fiber table developed by Skytron incorporates many of these features (Figure 11.12). This table has recently been modified to confer multiple advantages to the endourologist performing renal access for PCNL [29]. Included among these are a large, unobstructed imaging window that can be used with a C-arm rotated in even the most extreme positions, as well as the ability to position the patient in lithotomy, allowing access to the perineum. One disadvantage of this table is the inability to flex the patient for the prone–flexed position.

Anatomic considerations: renal axis and mobility

Knowledge of renal and retroperitoneal anatomy is essential to performing PCNL with minimal patient morbidity and low risk of iatrogenic organ injury. The kidneys lie in the retroperitoneum with the psoas muscle lying posteromedially, which results in the long axis of the kidneys being deviated so that the upper pole is more medial in the coronal plane. The upper pole is also closer to the posterior abdominal wall and more densely attached to Gerota's fascia [30]. The lower pole is more anterior and freely mobile. These findings can easily be appreciated during open and laparoscopic renal surgery.

There are several implications to these findings. First, puncture of the lower pole may be slightly more difficult as the freely mobile lower pole moves away from the needle and dilators. Second, lower pole tracts tend to be longer and more oblique, making stone removal from upper calyces with rigid instruments more difficult than the converse (Figure 11.13). Percutaneous access into the upper pole is simplified by the more dense attachments of Gerota's fascia, reducing mobility, and the shorter distance from the skin compared to into the lower pole.

Complications of percutaneous nephrolithotomy (see also Chapters 30–32)

Organ injury

Several anatomic studies have attempted to define the relationship of organs to the target kidney and nephrostomy tract. However, the position of the kidneys within the retroperitoneum is dynamic, changing with both respiration and body position. We and others have demonstrated that when the patient is positioned in the prone or prone–flexed positions, the spleen and liver rotate laterally, away from the kidneys and nephrostomy tract, compared to when the patient is positioned supine [31]. This would make it less likely that either of these organs would be injured with a puncture 30° from the vertical [10]. A study using images from reconstructed magnetic resonance imaging (MRI) scans reaffirmed the preference for more medial puncture to avoid iatrogenic injury to the spleen and liver [32].

Several studies have utilized both CT and MRI to study these changes and estimate the relative risk of iatrogenic organ injury during renal puncture. Organs at risk from upper pole puncture include the liver, spleen, and pleural space [32–34]. In contrast, the colon is most at risk from lower pole access [35]. Risk of organ injury varies considerably amongst published reports. In one study, the predicted risk of injury to the liver or spleen with upper pole puncture was approximately 15%, but decreased to zero by changing body position from supine to prone [33]. In contrast, the same group found that the incidence of retrorenal colon was 4.7% in the prone position and 1.9% in the supine position [36]. In a study of axial and multiplanar reformatted CT scans, Tuttle *et al*. demonstrated that axial CT scans may dramatically overestimate the risk of injury. The risk of organ injury associated with lower pole puncture on axial CT was 6.0% in the supine position versus 15.1% with the patient prone; however, for oblique parasagittal CT reconstructions, the risk was decreased to 3.0% and 0%, respectively [35]. These findings are more in keeping with clinical series demonstrating low rates of organ injury. The lack of a standardized approach may also account for the variability in these reports. In the largest clinical series, the rate of bowel injury was 0.06% of almost 1600 procedures, with no cases of splenic or liver injury [17]. Others have reported similarly low rates of organ injury [11, 12, 37]; however, in some series, access was obtained in the radiology suite.

Valdivia Uria *et al*. and Falahatkar *et al*. state that the colon "floats away from the kidney when the patient is in the supine position" [9, 16]. Our CT studies did demonstrate that the colon was more medially situated and theoretically more prone to injury in the prone and prone–flexed positions compared with the supine position; however, the overall effect was minimal. Anatomically the colon is attached laterally to the peritoneum of the side wall of the abdominal cavity at the level of the kidneys and movement is restricted. The more lateral approach of the supine position would therefore still be more likely to result in the rare complication of colonic injury, which has been reported in this position [38].

Thoracic complications

The risk of pleural injury is of considerably greater concern. The diaphragm inserts onto the 12th and 11th ribs with the pleural reflection running horizontally and crossing the midpoint of the 12th rib in the majority of patients. The risk of pleural injury is therefore related to the position of the kidney in the retroperitoneum, the pleural reflection, and the calyx chosen for access. The majority of pleural complications occur with upper pole access. Significant complications include pneumothorax, hydrothorax/hemothorax, and empyema. In a study by Munver *et al*., the incidence of thoracic complications was 23.1% above the 11th rib, but dropped to just 1.4% above the 12th rib. The overall complication rates ranged from 4.5% for subcostal access to 9.7% above the 12th rib, and 34.6% above the 11th rib [39]. We have previously demonstrated that prone–flexed positioning results in inferior displacement of the kidneys within the retroperitoneum, an effect which could result in fewer thoracic complications [10]. In an update of our previous report including data from the last 318 patients in our unit to be treated in the prone–flexed position, 16 (5.4%) of the tracts were above the 11th rib, 120 (40.8%) were above the 12th rib, and 158 (53.7%) were infracostal. There were only four pleural complications requiring chest drain insertion, representing 2.6% of the supracostal cohort [40].

Hemorrhage

To prevent bleeding, the most important aspect is the end-on puncture of a posterior calyx. Using 3D polyester resin endocasts, Sampaio *et al*. demonstrated that the risk of arterial injury was highest from infundibular puncture and that the calyceal fornix provided the safest route of access [41]. Normally, the upper pole of the kidney is more medially and posteriorly located than the lower pole. Consequently, an upper pole posterior calyceal puncture lateral to the paraspinal muscles will result in access being more in line with the axis of the kidney. This will result in less torquing of the kidney to reach the lower calyces and less chance of the parenchyma splitting and bleeding (Figure 11.13). An angled tract that is not in line with the infundibulum or renal axis, or a puncture of the lateral calyces will require more torque to reach the stone, which may result in unnecessary bleeding and increased transfusion rates. Choice of the appropriate percutaneous tract through a posterior calyx in line with the infundibulum will allow the operator to achieve a transfusion rate for PCNL of approximately 1% [17]. In an update of our previous report reviewing data from our most recent 318 consecutive patients, no patient required blood transfusion or angioembolization [40].

Complications specific to patient positioning

Anesthetic considerations (see also Chapter 8)

Anesthetic concerns garner much attention in prone percutaneous surgery and have been the driver of much of the renewed interest in supine PCNL. The greatest risk of airway loss is when the patient is positioned prone. For this reason, secured endotracheal anesthesia is preferred [42]. However, even with a cuffed endotracheal tube, problems may occur. Obstruction of the tube may occur due to kinking or secretions draining under gravity in this position [43]. Fortunately, such concerns remain largely theoretical and complications are limited to case reports.

Another concern has been the maintenance of prone anesthesia in obese patients or those with cardiovascular or respiratory compromise. Although we have found that the prone–flexed modification may further increase airway pressures in obese patients, necessitating a reduction in patient flexion, we have not found it necessary to revert to conventional prone positioning. As with other authors, in the morbidly obese patient, we favor lateral or lateral–flexed positioning as this avoids abdominal compression and allows the anesthesiologist free access to the patient's airway [2, 3]. Others have reported using the lateral decubitus position in high-risk patients under regional anesthesia [44], as well as awake endotracheal intubation with prone self-positioning [23] as ways to overcome these difficulties.

Cardiovascular changes

The greatest body of research related to the effects of prone and prone–flexed patient positioning comes from spinal surgeries, where the impact of patient position on both physiology and surgical outcome has long been recognized. Hemodynamic changes related to patient positioning remain controversial and likely depend on the underlying cardiovascular status of the patient, the precise body position, and the use of saddles/bolsters. It is generally agreed that prone positioning causes a decrease in cardiac index (CI). However, this is not felt to be clinically significant. In a study of 19 patients, Hatada *et al*. concluded that the drop in CI presented no significant challenge to the maintenance of anesthesia [45]. Other groups have also reported this finding [46, 47]. In the prone and prone–flexed positions, mean arterial pressure (MAP) appears to be maintained due to an increase in systemic vascular resistance [47].

Prone positioning may also lead to transient IVC obstruction. In spinal surgery, this has led to speculation that impeded venous drainage may contribute to increased bleeding during surgery [48]. Whether this may also play a role in blood loss during renal surgery remains unknown. It has been shown that relieving abdominal compression by placing a bolster under the patient's chest and padding of the anterior superior iliac crests can dramatically decrease the effect [49].

In rare circumstances, cardiac resuscitation may be necessary in the prone patient. When possible, it is advisable to return the patient to the supine position and to have a stretcher standing outside the OR for this purpose. This allows access to the precordium for both chest compressions and defibrillation. However, when there is need for prolonged delay in repositioning due to instrumentation protruding from the flank, successful resuscitative efforts with the patient positioned prone have been reported [50, 51].

Respiratory changes

As with cardiovascular changes, changes in pulmonary physiology vary considerably with patient position, body habitus, and the amount and type of padding/support used. Although tidal volumes and inspiratory flow rates are preserved in the ventilated patient, functional residual capacity (FRC) consistently increases with a change from supine to prone position [42]. One study found that prone positioning did not significantly affect compliance and that respiratory resistance increased only slightly in nonobese patients. As both FRC and PaO_2 markedly increased from the supine to the prone position, the authors concluded that during general anesthesia, prone positioning did not have a negative effect on respiratory mechanics, instead improving both lung volumes and oxygenation [52]. Interestingly, these improvements were maintained in a similar study in anesthetized and paralyzed obese patients in the prone position [53]. It has been hypothesized that improvements in gas exchange may be due to changes in pulmonary blood flow and redistribution of lung ventilation, resulting in better V/Q matching [42]. Importantly, the requirement for free abdominal and chest-wall movement cannot be overemphasized in the surgical patient.

Ophthalmic complications

Eye injuries resulting from surgery are extremely rare, with an incidence of approximately 0.1% following nonocular surgery [54]. Corneal abrasions account for the majority of these injuries, but rarely result in vision loss. In the prone position, there is also a theoretical risk of blindness, due to increased intraocular pressure resulting in ischemic optic neuropathy (ION). Fortunately, this complication is rare and has mainly been reported during spinal surgery, especially with prolonged OR times in excess of 6 h in the prone position [55, 56]. We are unaware of any cases following PCNL.

Nerve injury

Positioning-related peripheral nerve injuries occur secondary to stretch, ischemia, or compression. The combined factors of time, mechanical pressure, and immobility place patients at risk for these complications. Recovery can be variable and is directly related to the severity of the injury.

Special care must be taken with patients in the prone position as they are susceptible to brachial plexus injuries [57]. Such injuries are most commonly due to nerve stretch from extreme shoulder abduction; however, external compression can also play an important role. Prolonged surgical procedure has also been suggested as a contributing factor. Typically, these injuries present as painless motor dysfunction. To prevent this complication, some authors recommend tucking the arms at the patient's side during the procedure. We find that abduction of the shoulder to approximately 90° with elbow flexion relieves undue stress. Ideally, the arm should be well padded and rest below the level of the patient's chest. Additionally, for patients in the prone and prone–flexed positions, the head must be maintained in a neutral position to prevent lateral flexion. Fortunately, the prognosis for these injuries is usually good. In one study, following a cohort of 22 patients with brachial plexus injury, including 14 following noncardiac surgery, complete recovery was achieved in 79% [58].

Nerve compression injuries may also occur in other operative positions. In the lateral position, the ulnar nerve is at risk from the edge of the OR table. The majority of these injuries can thus be prevented by adequate padding at the elbow and supination of the dependent arm [59]. In particular, flexion of the elbow of greater than 90° is a known risk factor and is due to shrinkage of the cubital tunnel, resulting in compression of the nerve [60].

Injury to the peroneal nerve has commonly been described in association with the dorsal lithotomy position. Many surgeons use Bierhoff leg holders when placing patients in this position. Long duration of the procedure has been implicated in this type of injury [61]. General guidelines for use of these supports include: (1) slow and simultaneous placement of the legs into their final position, and (2) limiting the amount of hip flexion, abduction, and lateral rotation [57]. In the lateral decubitus position, compression of the unpadded fibular head against the OR table during nephrectomy resulted in peroneal nerve injury in one patient [62].

Sciatic nerve compression between the OR table and the ischial tuberosity has also been known to occur in patients in the semi-lateral position as well as in the lithotomy position [57, 61].

Fortunately, the great majority of intraoperative nerve injuries are preventable. A high level of suspicion is important when recognizing these injuries as patient complaints in the early postoperative period may be easily dismissed. With careful attention to patient positioning, the use of adequate padding, and awareness of patient comorbidities such as skeletal deformity are all essential components. When nerve injuries do occur, prompt referral to a neurologist who specializes in these types of injury is required.

Prone versus supine percutaneous nephrolithotomy

In an attempt to overcome some of the difficulties associated with prone positioning, there has been a resurgence of interest in PCNL performed with the patient supine (Table 11.3). The first report on supine PCNL, by Valdivia Uria *et al*. in 1998, included 557 patients [9]. In this position, puncture is performed under fluoroscopic or ultrasound guidance either in or anterior to the posterior axillary line (see Chapter 10). This distinction is important as the resulting tract is significantly more lateral than the access used in prone or lateral PCNL. In their original report, Valdivia Uria *et al*. expressed a preference for puncture of anterior calyces, with low complication rates; however, transfusion rates were not reported. Other authors have similarly found that puncture of anterior calyces is often necessary in the supine position [15, 63]. As noted above, rates of adjacent organ injury are rare when performing PCNL. In his original report, Valdivia Uria stated that the colon "floats away from the kidney when the patient is in the supine position" [9]. Our data from axial, triphasic CT scans performed with the patient prone, prone–flexed, and supine supported this statement. However, the overall effect was small and would likely be mitigated by the more laterally placed tracts necessary with supine PCNL. Of 1720 supine procedures reported in the literature to

Table 11.3 Summary of the supine/Galdakao-modified supine Valdivia (GMSV) patient position.

Technique	Advantages	Disadvantages
Originally performed with the patient supine and the ipsilateral leg fully extended A 3-L saline bag is placed under the ipsilateral flank GMSV includes modified lithotomy position with extension of the ipsilateral leg and abduction of the contralateral leg	May perform ureteroscopy and nephroscopy simultaneously Patient repositioning is unnecessary Improved surgeon comfort Theoretically reduced radiation exposure Stones may spontaneously evacuate at calyx of entry due to dependent drainage Fewer cardiovascular and respiratory effects May be performed without endotracheal intubation	Instrument movement is limited by the OR table and the patient's hip Pelvicalyceal system is collapsed and may contain air, impairing visibility Upper pole puncture is more difficult or impossible Many calyces are dependent and collect fragments Placement of multiple tracts is difficult, limiting use in staghorn calculi Results in longer nephrostomy tracts, sometimes requiring longer instruments Longer OR times when treating staghorn stones Ventilation may be impaired in morbidly obese patients May be associated with higher transfusion rates

date, only one case of bowel injury has been reported (0.00058%) [38].

Bleeding following PCNL is another area that deserves attention. A review of all studies published to date demonstrated an overall transfusion rate of 4.6% (range 0–20%) with PCNL performed in the supine position [15, 16, 38, 63–72]. The higher transfusion rates may be partly due to renal shear, as puncture of an anterior or lateral calyx in the lower pole would result in more manipulation when using a rigid endoscope to access the full length of the collecting system. Additionally, end-on fluoroscopic views of the calyces in this position are obstructed by the patient's spine and side-rails of the OR table, particularly in oblique views. As a result, the triangulation method of fluoroscopic puncture may be necessary or, more commonly, ultrasound-guided access. In the latter case, special expertise may be necessary to perform end-on calyceal puncture to avoid the intrarenal arterial injuries that can be the cause of profuse bleeding during PCNL [41]. Four studies have performed a direct comparison of prone and supine positioning during PCNL by the same surgeon [15, 16, 38, 63]. Due to small sample sizes, no significant difference in transfusion rate was noted by any group. However, when considered together, the transfusion rate for PCNL performed in the supine position was 8.8% versus 4.3% when performed prone (182 and 207 patients, respectively; $P = .07$).

An argument given by proponents of the supine technique has been that it is more ergonomic, and facilitates stone clearance through spontaneous evacuation from the dependent nephrostomy tract. However, in this position, stone fragments also collect in the dependent posterior calyces rather than the renal pelvis, as is the case when the patient is prone. Dependent nephrostomy drainage in this position also results in a collapsed system, often containing air bubbles that may interfere with visualization. Finally, the supine position can also result in restricted mobility of the nephroscope due to conflicts with the OR table.

In a review, de la Rosette *et al*. examined the effect of patient positioning, concluding that for obese patients or those with staghorn calculi, the prone position was associated with similar bleeding rates, but decreased operative times, and slightly improved stone-free rates compared to the supine position [73].

Conclusions

Appreciation of the calyceal anatomy and the ability to choose the appropriate posterior calyx for percutaneous access in the prone position will allow the operator to perform the procedure with minimal morbidity. Prone–flexed positioning is a simple modification that is well tolerated by the patient and offers significant surgical advantages. The lateral position is well-suited to the morbidly obese patient, while the lateral-flexed position adds further advantages and is familiar to all urologists.

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CHAPTER 12

Percutaneous Renal Access Under Ultrasound Control

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Introduction and indications for ultrasound-guided renal access

Percutaneous renal access can be achieved either with ultrasound or fluoroscopy guidance. The method of choice depends on training and personal preference. The side effects of extensive radiation during therapeutic procedures are well-known, which is the main drawback of fluoroscopy [1]. Ultrasound has several strengths as an interventional tool. It is readily available, relatively inexpensive, and portable. It has no radiation and provides guidance for access in multiple, transverse, longitudinal, and oblique planes. Its greatest advantage is use for realtime monitoring of the needle tip, which guides proper placement of the needle and avoidance of important viscera. An added advantage is that it can be used in conjunction with Doppler to avoid important vascular structures lying along the needle path.

Percutaneous ultrasound-guided access is the simplest and most direct technique to drain a hydronephrotic collecting system. It is most often utilized to place a temporary urinary diversion because of an obstructing stone or pyonephrosis .It has also been used successfully to relieve upper tract obstruction secondary to malignancy. Ultrasound-guided nephrostomy puncture is preferred for patients in whom retrograde ureteral access is unsuccessful. It is also a method of choice in pregnancy when there is a need for deobstruction. Allergies to topical or injectable local anesthetic and coagulopathy are the only relative contraindications to ultrasound-guided renal access [2].

The ultrasound-guided approach has proven to be safe and efficacious in the pediatric population [3], renal stones in transplanted kidneys [4], and pelvic renal ectopia [5].

Contemporary issues regarding ultrasound as a method to guide access are:

- Who should achieve access – urologists or radiologists?
- How should they be trained?
- Is there is any difference in the outcome for ultrasound- and fluoroscopy-guided access?
- What should be the technique of achieving access? Ultrasound versus fluoroscopy?

In this chapter, we discuss these issues in light of the existing literature. We also describe our technique of achieving percutaneous renal access with ultrasound.

Instrumentation

Types of transducers

The "transducers," or "scanning probes" as they are known, are the most important and expensive component of the ultrasound machine. The transducers emit ultrasound pulses and receive echoes during scanning. Ultrasound access requires a dedicated transducer with an ultrasound frequency ranging from 3.5 to 5.0 MHz. The monitor used for intervention should ideally be equipped with an electronic dotted line which shows the needle path. The needle guide that is attached to the ultrasound transducer helps prevent needle displacement from its proper trajectory.

Sector probes

The scans from these probes are fan shaped. These scanners can be used when the space for scanning is narrow

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as they show a very small acoustic window, and are primarily used in gynecologic and cardiac ultrasound. They can be useful when performing nephrostomies in the pediatric age group.

Convex probes

These probes produce rectangular scans and are most commonly used for gaining percutaneous renal access.

Linear array probes:

These probes are most commonly used for scanning the breast and thyroid.

The ideal transducer for renal access is a convex transducer of 3.5 MHz, focused at 7–9 cm. If such a transducer is not available, then either a linear or sector transducer of 3.5 MHz is necessary. If children or thin patients are to be scanned, then a 5-MHz smaller transducer with a focus at 5–7 cm is required. Alternatively, a sector probe can be used in this situation (Figure 12.1).

Access needles

Using an 18G needle to access the renal collecting system helps with the introduction of a 0.035- or 0.038-inch guidewire into the collecting system. When ultrasound-guided access is to be achieved, the rigidity of the 18G needle compared to the 21G needle is advantageous for accurately directing the needle tip as it is advanced through the fascial planes. The 18G needle tip is also readily identifiable with realtime ultrasonography guidance. Although routine needles can be used for this purpose, the echo tip needle (Cook Medical Inc, Bloomington, IN, USA) is helpful in achieving ultrasound-guided access; the needle tip is scored and this increases the reflectivity and visualization on ultrasound. The needles are available in three or two parts (Figure 12.2). The three-part needle is useful for instilling contrast after ultrasound-guided puncture as the needle does not need to be removed from the puncture guide. Another variant of the needle has a Teflon sheath which allows instillation of contrast and a guidewire .

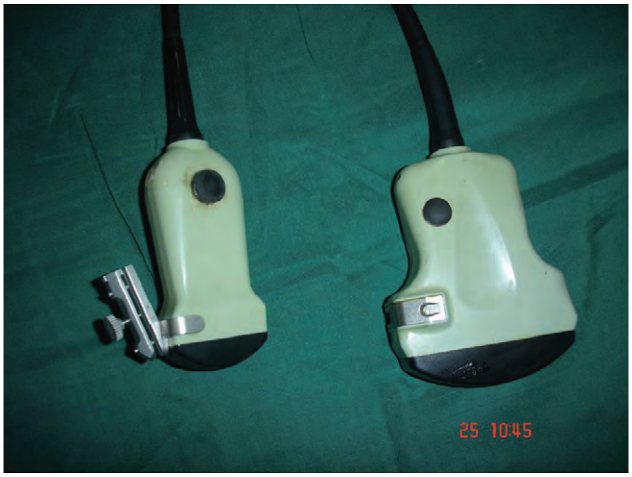

Figure 12.1 Smaller probes help in gaining access in children. The puncture guide attachment helps direct the needle.

Ultrasound technique

Orientation and calibration of the image

Before starting, it is necessary to visually check which side of the transducer produces which side of the image. Although most of the times there is an indicator on the ultrasound probe for orientation, this is best done by placing a finger at one end of the transducer and seeing where it appears on the screen; if the orientation is incorrect, the transducer should be rotated through 180°. On renal scan the liver or spleen helps in orienting the upper pole.

The machine should be calibrated properly before use and in such a way that there is a black background with white echoes [6].

Needle visualization

Clear visibility of the needle is "key" to the success of ultrasound-guided needle access (Figure 12.3). The most common reason for nonvisualization of the needle tip is nonalignment of the needle tip and transducer. This can be achieved by proper alignment. Although alignment is challenging "freehand", it will improve with experience and occasionally a mechanical attachment can be used [7].

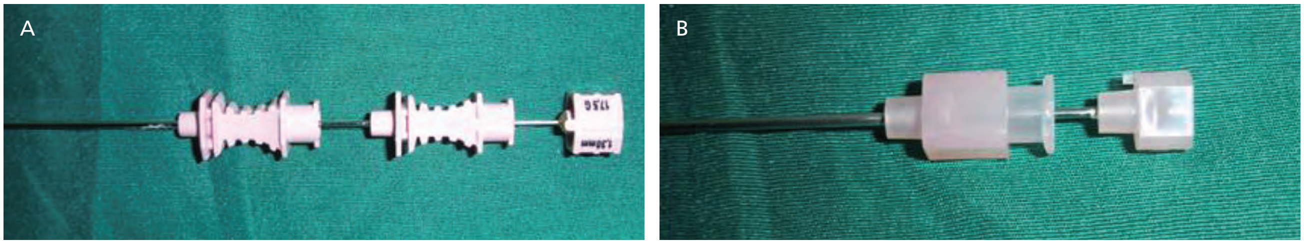

Figure 12.2 (A) Three- and (B) two-part needle.

If the needle is not visualized it may be either off centre or angled away from the transducer. A "bobbing" or "in–out jiggling" movement of the tissue in the superficial plane helps decide the path of the needle. This movement also helps push the soft tissue away from the needle path and clear visualization of the needle[7].

A few other ways in which the needle can be better visualized are by increasing the reflectivity using large caliber needles, scoring the needle tip (see above), and keeping the bevel of the needle facing upwards.

Ultrasound-guided access with a needle guide

This is the method of choice for ultrasound-guided access at our center. We use the 3.5/5-MHz probe (Profocus™, B & K Medical, Denmark) with a Doppler attachment. We typically keep one bolster under the patient's lower chest and the other at the level of the iliac crest. We consider that with the patient in the prone position and bolsters in these positions, the bowels and viscera tend to drop down, thus minimizing the chance of bowel injury.

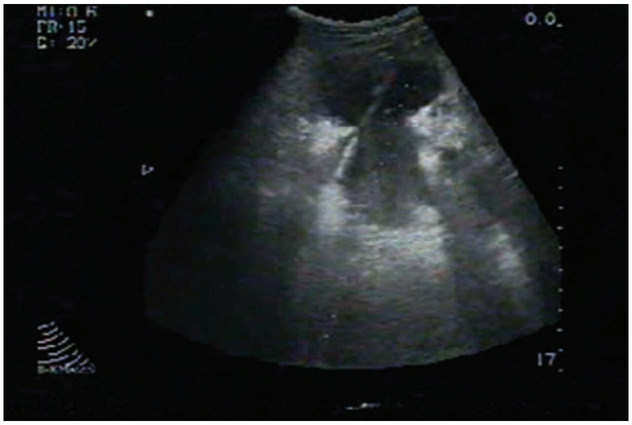

Figure 12.3 If the needle is aligned properly, then the shaft of the needle is visualized throughout its course.

Ultrasound scanning commences posteriorly and proceeds until the posterior axiliary line. If scanned in this way, the first calyx to be seen will be the posterior calyx. The site of needle entry is marked and the puncture performed with an 18G echo tip (Cook Medical Incorporated) needle. The key point at this crucial step is that there should be minimal respiratory and ultrasound probe movement. In order to ensure an accurate puncture, the needle tip should be seen along the electronic dotted line throughout its course. The position of the needle in the desired calyx is confirmed with return of clear fluid.

The attributes of a perfect renal access are shortest possible and straight tract, traversing the skin, cortex of the kidney, and cup of the desired calyx of puncture (Figure 12.4). We consider that ultrasound-guided access maximizes the chances of this. We have been successfully performing access with ultrasound guidance in percutaneous nephrolithotomy (PCNL) with patients in the supine position; this has also been performed in the pediatric population [8, 9].

Ultrasound access without a needle guide

These ultrasound transducers do not possess an electronic dotted line or puncture guide. The operator places the probe and scans the relevant renal unit. The probable path of the needle is marked and access is gained.

Alternatively, in grossly hydronephrotic kidneys, the ultrasound probe helps with access in the paraspinal area, which is used for opacification of the pelvicalyceal

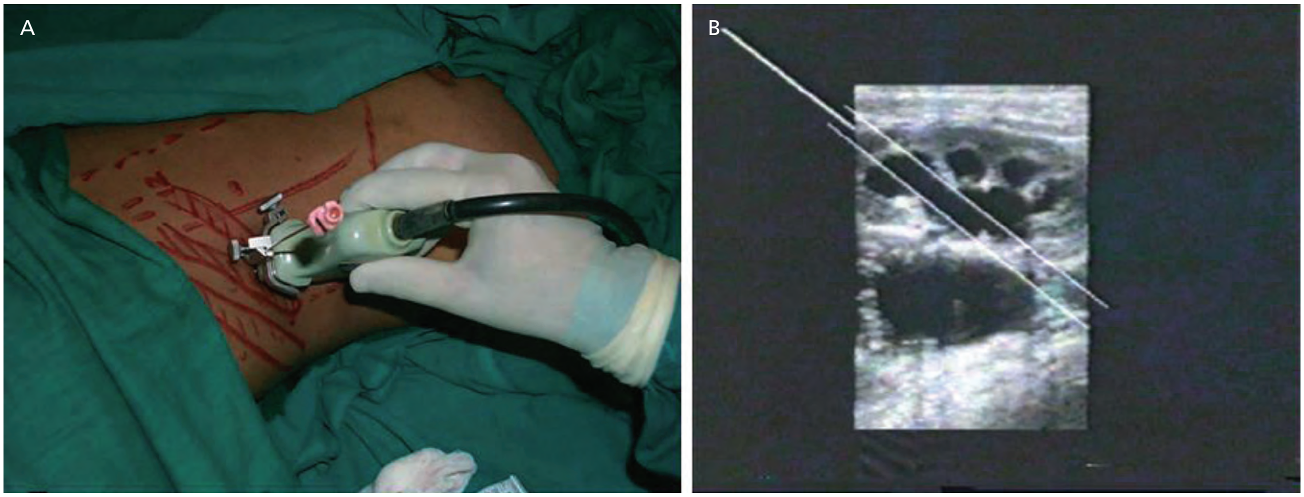

Figure 12.4 (A) The puncture guide helps in directing the needle in the desired plane and depth. (B) The ultrasound probe should be aligned in such a way that the tract provides the shortest access from the skin through the cup of the calyx, infundibulum, and finally into the pelvis.

Image not available in the electronic edition

Figure 12.5 Technique of ultrasound-guided puncture of a pelvic ectopic kidney. USG, ultrasound guided (reproduced from Desai & Jasani [5], with permission).

system and subsequent fluoroscopic–guided puncture in a appropriate calyx.

The serious limitation of the technique is that although the ultrasound probe shows the kidney and calyces, the image is devoid of depth and does not show the plane of the path that the needle traverses; as a result the chance of visceral injury increases. Ultrasound-guided puncture with a Doppler guide is of help in abnormal renal anatomy, such as horseshoe kidney and malrotated kidneys.

Application of ultrasound in special situations

The various drawbacks of PCNL in the conventional (prone) position include the need to turn the patient from the supine to prone position, risk of tube dislodgments, and neuropraxias. In addition to severe kyphoscoliosis, morbidly obese patients with heart and lung conditions do not tolerate the prone position well. Ultrasound-guided renal access is of value in such situations. Ultrasound-guided punctures are also of value in emergency situations, such as percutaneous nephrostomies in obstructive uropathy in pregnancy [8, 10].

Ultrasound punctures in ectopic kidneys and transplanted kidneys

The management of calculi in ectopic kidneys is a hotly debated topic, given that a number of treatment modalities, including laparoscopic-guided PCNL, are available. At our center we have been performing PCNL in these cases under ultrasound guidance. Preoperatively the side-to-side mobility and ability to displace the kidney in relation to the abdominal wall is assessed. The site of the puncture is the iliac fossa. A supine oblique position with a bolster under the ipsilateral hemipelvis is used. A mechanical bowel preparation with a low enema is used in all the cases. This helps in identification of gas in the sigmoid colon, which helps identify the bowel and prevents possible injury. Pressure on the ultrasound probe helps to displace the intervening bowel loops between the puncture line and targeted calyx. Similarly, contralateral pressure applied by the assistant helps displace the kidney close to the abdominal wall. All these maneuvers improve the chances of achieving a straight, short, and direct tract to the desired calyx (Figure 12.5).

PCNL is feasible in transplanted kidneys with the help of ultrasound-guided access and this decreases the amount of radiation and intravenous contrast required. With the patient in a left-sided oblique position with a bolster under the ipsilateral hip, the bowel is displaced and a puncture into the superior calyx provides easy access to the ureteropelvic junction and stone in the pelvis [4].

Preceptorship and mentoring

Competence in ultrasound-guided renal access requires a learning curve to be overcome. The mentoring should start from the residency training itself. At our center training is structured. The trainee initially performs the ultrasound in the outpatient department; later, in the first year of training, they perform ultrasound-guided percutaneous nephrostomies in grossly hydronephrotic systems, and by the end of third year ultrasound-guided punctures for PCNL for renal calculi. We believe this approach shortens the learning curve by giving the trainee insight into the intricacy of aligning the needle with the transducers.

A variety of models have been described for training in ultrasound. Hacker *et al*. have developed the biologic model using a chicken carcass and fresh *ex vivo* porcine kidney. The laboratory model used routine PCNL equipment. For imaging, ultrasound (7.5 MHz) and a fluoroscopy unit are necessary. This model simulates realistically the clinical procedure of PCNL under ultrasound guidance. In addition, it is low cost and takes little time to prepare, and there are no legal issues involved. The drawback of this model is that it gives no tissue feel and lacks simulation of respiratory movement [11]. Mozer *et al*. described a system in which the ultrasound image was projected on fluoroscopy. The system consisted of a computer and localizer, allowing spatial localization of the position of the various instruments. Without any human intervention, the ultrasound nephrostomy tract is superimposed in realtime onto fluoroscopic images acquired in various views. In this study the possibility of fusing images derived from two imaging sources was explored. [12].

Urologist or radiologist?

Many urologists do not perform percutaneous access routinely, especially in the USA and some parts of Europe. Despite evidence that urologists can safely acquire percutaneous renal access for percutaneous nephrolithotomy, many centers still rely on interventional radiologists to obtain renal access. In our opinion, the urologist is better suited for making the access. Apart from being technique oriented, their insight into the disease process helps improve outcome.

El-Assmy *et al*. studied access achieved by a urologist with that by a radiologist; both groups of patients were comparable demographically except that the group treated by the urologist had a higher risk of multiple stones and multiple tracts. The stone-free rates and complication rates were comparable. Multivariate analysis showed that bleeding was not related to whether access was performed by a urologist or radiologist. They concluded that urologists can safely and effectively obtain percutaneous renal access for percutaneous nephrolithotomy as a single-stage procedure [13]. Another study revealed that despite similar access difficulty between groups, access-related complications were less and stone-free rates were improved when a urologist acquired percutaneous access. Urologists trained in percutaneous access may be able to provide improved stone-free rates during PCNL while minimizing access-related complications [14].

To accomplish this, it is essential that the urology residency program should include training in the technique of percutaneous access, as recommended by El-Assmy *et al*. [13]. It is important to recognize that PCNL has a relatively long learning curve. The fact that kidney puncture and access is a major step for PCNL success highlights the importance of training urologists in this surgical step [15].

Ultrasound versus fluoroscopy (see also Chapter 11)

Access to the renal collecting system with fluoroscopy has the disadvantage of inability to visualize surrounding structures, such as bowel or solid organs, and need for cystoscopy and retrograde contrast instillation for opacification of the system. Percutaneous access with fluoroscopic guidance is more challenging than with ultrasound guidance [16]. The ultrasound-guided approach is safe with a very low risk of major complications. We consider ultrasound is more precise in achieving access, at times, as all the calyces are not filled on opacification.

Level 1 evidence comparing ultrasound and fluoroscopy is scant. In a clinical trial, 100 patients with no abnormality of the upper urinary tract were selected from among candidates for PCNL and randomly assigned to two 50-patient groups: ultrasound-guided access (group 1) versus fluoroscopy-guided access (group 2). Duration of the access procedure was 11 ± 3.5 min and 5.5 ± 1.7 min in groups 1 and 2, respectively ($P = .0001$). Duration of radiation exposure, on average, was 0.69 ± 0.26 min and 0.95 ± 0.44 min, respectively ($P = .0001$). They concluded that access for PCNL using ultrasound guidance is an acceptable alternative to fluoroscopy and decreases radiation hazards [17].

Zegel *et al*. compared 55 patients with ultrasound access with 33 patients with fluoroscopy access A significantly reduced number of puncture attempts was noted with ultrasound-guided access (1.2 vs 4.1) [18] , thus significantly reducing the length of time for the procedure.

In our study comparing the two methods of access, the decrease in hemoglobin and hematocrit was significantly less in the ultrasound group [3]. The number of attempts required to achieve a successful puncture was also significantly less in the ultrasound group.

Ultrasound-guided access has also been described in the nondilated system [19, 20]. The fluid infusion technique used to make the pelvicalyceal system more prominent has been described to achieve access in such situations [21]. Total ultrasound-guided PCNL has been described [22]. The authors describe that while gaining access the transducer is placed posteriorly while during dilation it is placed on the anterior abdominal wall for better visualization of the dilators. Anterior placement is possible as the patients are placed in the flank position. Although feasible, this procedure requires significant experience and the dilators must be visualized throughout the procedure to avoid under- or overdilation (Figure 12.6).

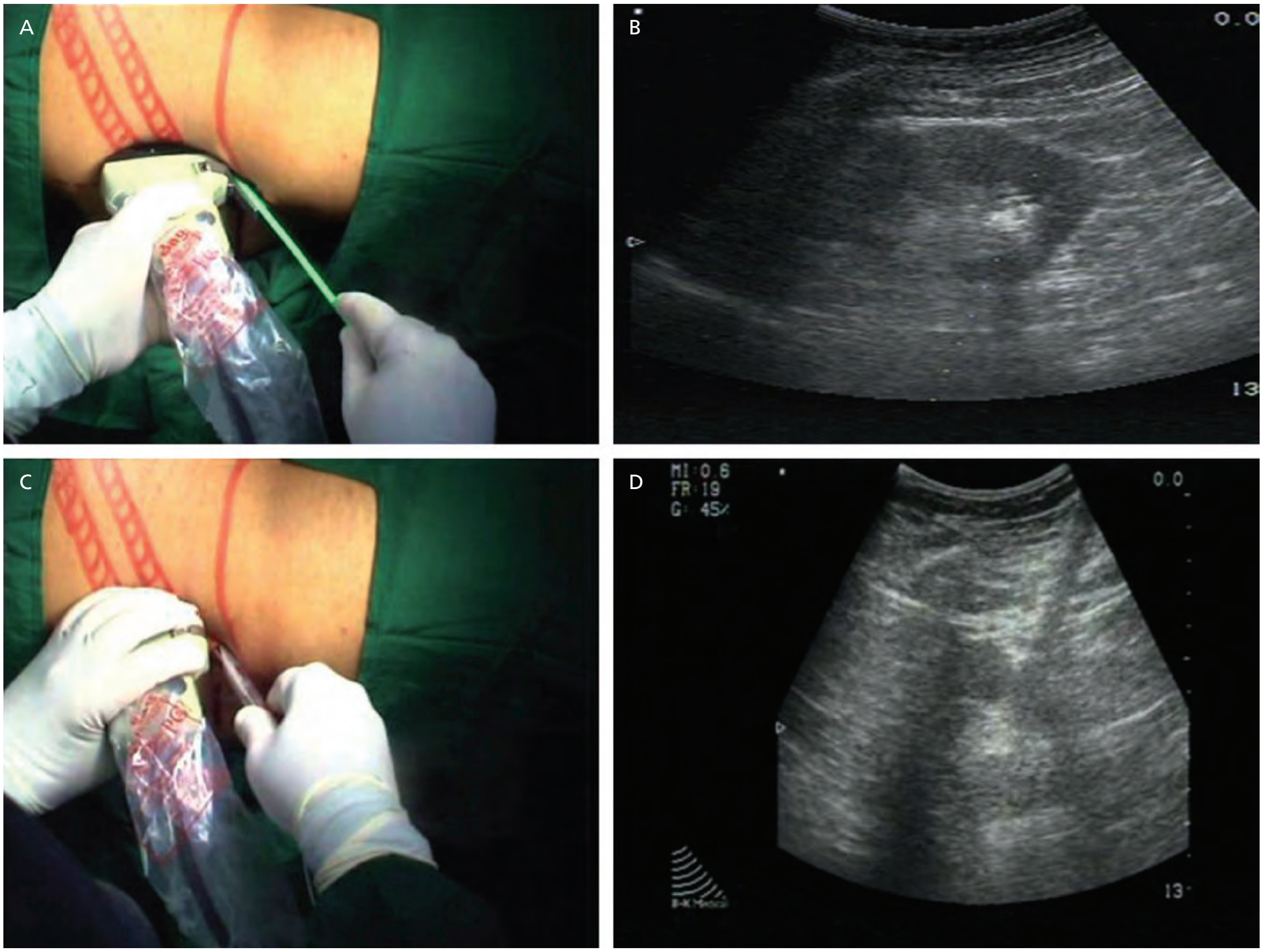

Figure 12.6 (A) Puncture is performed under ultrasound guidance. (B) The needle is visualized along the electronic dotted line. (C) The tract is dilated under realtime ultrasound guidance with a balloon dilator. (D) The balloon can be seen under realtime ultrasound guidance

Conclusions

The role of ultrasound and fluoroscopy are synergistic. Ultrasound-guided access is the method of choice in deobstruction of the upper tract in failed retrograde access, malignancy, and pregnancy. It also helps in PCNL in transplanted or ectopic kidneys. This technique requires considerable experience and training in it should be structured and begin in residency.

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CHAPTER 13

Percutaneous Renal Access Under Fluoroscopic Control

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The last years of the 1970s and the early 1980s will probably be remembered by urologists as a time of tremendous changes, in particular the whole concept of minimally invasive surgery and the development of percutaneous surgery, which have shown spectacular clinical results and reduced the morbidity of open surgery [1]. Percutaneous stone extraction was first described more than 30 years ago and has become an increasingly common intervention for patients with stone disease [2, 3], evolving into a safe and effective treatment for patients with large or otherwise complex stone disease. However, despite the increasing use of percutaneous renal surgery, Lee *et al*. reported that only a minority of urologists, 27% of who have trained in percutaneous access, actually gain their own access for percutaneous nephrolithotomy (PCNL) [4]. One of the more common reasons given by respondents for not doing so was inadequate skills in the techniques of access.

The placement of percutaneous access into the intrarenal collecting system is one of the most critical aspects of percutaneous renal surgery. Image guidance is a critical factor for the performance of percutaneous minimally invasive procedures, which are being used with ever increasing frequency. Procedures such as PCNL are not performed without image guidance. The puncture of the kidney, insertion of guidewires, establishment of the percutaneous tract, and the disintegration and removal of stones are based on appropriate image guidance. For percutaneous renal surgery using fluoroscopy, access must be gained: different forms of access have been developed, all with the indispensable assistance of the image intensifier [5].

The first percutaneous nephrostomy to decompress an obstructed kidney was described by William Goodwin in 1955 [6]. However, removal of a renal calculus via a percutaneous tract established specifically for that purpose was not performed until 1976, when Fernstrom and Johansson used the technique successfully in three patients [7]. In their series, the tract was slowly dilated under fluoroscopic control over a 7-day period to a size sufficient for stone extraction. Similarly, Alken *et al*. in their experience with PCNL established access to the renal collecting system over the course of weeks, by repeatedly dilating it with hand-shaped polyethylene tubes of increasing size [8]. He subsequently developed the metal telescope dilators to solve the problems met during the treatment of his first 21 patients, which accelerates the procedure and allows percutaneous stone removal to be performed in a single session with a delicate set of instruments. In 1982, Smith *et al*. described the rapid dilation of the nephrostomy tract in minutes with no untoward effects, which revolutionized the field of percutaneous stone surgery and contributed to the demise of open surgery [9]. Since that time the percutaneous approach has generated wide interest among the pioneers of endourology, and they developed and popularized most of the basic principles in this area in the late 1970s.

Fluoroscopy

Imaging equipment in percutaneous renal surgery typically uses radiation for image formation and guidance during access and tract dilation.

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Fluoroscopy is useful during the advancement of guidewires, tract dilation, stone removal, and nephrostomy placement, providing realtime depiction of the collecting system and the stones therein. Percutaneous renal surgery is performed with a combination of fluoroscopic and endoscopic visualization of the collecting system. Fluoroscopy is a two-dimensional (2D) method and provides limited information regarding the surrounding soft tissue. Nevertheless, it has proven to be an invaluable tool for the performance of percutaneous procedures of the kidney and collecting system.

Radiation exposure

All parameters of fluoroscopy affecting image quality, reproducibility, and radiation output from each radiographic unit must be evaluated routinely to ensure optimal image quality while minimizing the radiation dose [10]. The endourologist can improve their imaging techniques and minimize both their and the patient's radiation exposure with no concurrent loss of image quality.

When attempting to obtain a diagnostic-quality image and the image is underpenetrated, and given the choice between increasing the total number of X-rays (mA) or the penetrability of the X-rays already present (kVp) to improve the image, the kVp should be increased initially as this will not increase the radiation output [11]. Collimating the image to the minimum size necessary for performing the work will reduce the amount of unnecessary radiation to which the patient and anyone else in the room is exposed.

The radiation output from the X-ray tube should have been evaluated within the past year by a radiologic physicist, who determines whether the unit's radiation output is within legal limits as well as optimal for each examination.

Radiation entering the patient is absorbed, scattered, or transmitted as a function of the density of the tissue it encounters. The contribution from tube leakage, and scatter from machine components and from the patient comprises the secondary radiation field and this is of the most concern to persons in the room during fluoroscopic imaging.

Radiation "spreads out" in a three-dimensional space with a discrete or fixed number of photons spreading out into successively larger spaces. As a result, the area geometrically increases as a function of distance from the source. Increasing the distance from the source is one of the least expensive and most dramatic ways to reduce the dose of radiation to which operating personnel are exposed. By doubling the distance from the source, the radiation is reduced to one-fourth of its original intensity because the same number of photons is in a space that is four times larger. Similarly, by tripling the distance, radiation is reduced to one-ninth. Moving 3 feet further away from an initial distance will reduce the dose by 89%.

Shielding, whether provided by lead aprons or thyroid shields, is a method of last resort. They provide excellent protection and should always be worn by those who work near the fluoroscopy table to limit the dose of radiation to which they are exposed. When fluoroscopy is performed, the radiation dosimeter badge is worn on the collar, outside the apron. As a result of this technique, the actual effective whole-body exposure is up to 99% lower than the dose measured by the badge [12].

Component positioning on the C-arm can significantly influence scattered radiation fields. When the image intensifier is placed above the patient, and the tube is shielded by the table, both leakage and scatter radiation are minimized.

The introduction of digital radiography has contributed to the reduction of radiation exposure as well as to the improvement of image quality [13]. The combination of digital radiography with image storage systems and use of image processing systems resulted in the prevention of unnecessary image duplication and facilitated preoperative planning. A new generation of equipment has been designed with patient and operator dose reductions central to its development. Pulsed fluoroscopy and digital imaging have become available that reduce the dose of radiation delivered to the patient. Digital equipment eliminates the need for film; the information is electronically captured and manipulated by computer. As a result, the image can be enhanced, providing a sophisticated tool for dynamically evaluating patient organ function using videotape techniques.

Radiation exposure can be a deleterious problem in percutaneous surgery, especially for the surgeon [14, 15]. The use of ultrasonography can eliminate the side effects of radiation exposure during fluoroscopy-guided PCNL, and it can be used as a reliable method for localization of renal stones, especially nonopaque stones that are not visible with fluoroscopy. Also B-scan sonography can be used as a tool for localization of intrarenal arteries and avoidance of puncture by a Chiba needle.

Ultrasound versus fluoroscopy-guided access (see also Chapter 12)

The advantages of ultrasound- over fluoroscopy-guided access into the collecting system include reduction of exposure to radiation for the urologist and operating room personnel. In pregnancy and in patients with transplanted, horseshoe, or ectopic kidneys, ultrasound represents the modality of choice [16, 17]. Another advantage is proper localization of the adjacent organs for prevention of injury. The main disadvantage of this modality is the difficulty and the need for greater care when the collecting system is only mildly dilated.

Ultrasound has been used by several groups for the guidance of PCNL, especially during the puncture of the collecting system [18].The performance of puncture with ultrasound guidance and without use of fluoroscopy has also been reported [19]. While ultrasound can be a useful complement to access the kidney, it should be emphasized that fluoroscopy is an indispensable component of safe percutaneous surgery.

Preoperative images

Conventional computed tomography (CT) has been used for diagnosis of urologic diseases for many years. Recently, unenhanced helical CT has become a serious alternative to intravenous urography [20]. For preoperative planning, helical CT depicts the extent, orientation, and location of renal calculi, which are useful for access selection in percutaneous procedures. In addition, the anatomic relationships of the collecting system with surrounding organs are delineated, and the performance of a safe puncture is possible [21]. Nevertheless, the inability to provide realtime imaging capability has prevented wider application of CT in interventional procedures [22].

The three-dimensional (3D) reconstruction of CT images for planning of percutaneous procedures has been reported to be feasible and accurate. With the use of 3D rendering software, the anatomic relationships of the collecting system are provided, and access selection is facilitated. The usefulness of 3D-reconstructed CT images, however, is not widely accepted [23]. 3D CT-rendered images that combine axial CT, CT urography, and angiography have been used for preoperative planning of urologic procedures, such as nephron-sparing surgery. Renal lesions and vessels can be accurately detected [24, 25]. Recent improvements in CT technology provide rapid and continuous reconstruction of CT raw data and provide realtime CT imaging (CT fluoroscopy) [26, 27].

Magnetic resonance imaging (MRI) provides better depiction of the soft tissue in comparison with fluoroscopy and CT, but remains unreliable for the identification of stones in the collecting system or ureter. MRI can be obtained without exposure to ionizing radiation. Thus, the technique may be considered as an alternative to ultrasound in selected cases such as the pregnant patient. Nevertheless, the strong magnetic field used interferes with ferromagnetic foreign bodies or electronic medical devices that are frequently carried by patients, although improvements in electronic medical devices have minimized this problem [28]. Newly introduced multisensor detector and faster image processing systems, as well as more advanced MRI scanners, have rendered realtime imaging a reality (MR fluoroscopy). The latter technique has been used in interventional cardiology [29]. Percutaneous nephrostomy placement has been performed with the use of open configuration MRI. MR urography represents an evolving imaging modality that allows optimal noninvasive evaluation of many abnormalities of the urinary tract. The application of several technical modifications provides adequate information for preoperative planning and postoperative assessment [30].

Each of these new technologies offers several potential advantages over the traditional percutaneous approach under fluoroscopic control. It should, however, be stated that all of these technologies are in a nascent stage of development. For that reason it is necessary to reinforce the basic concepts governing the realization of a conventional procedural approach to the kidney under fluoroscopic control. While this conventional approach is appealing, only a small percentage of urologists are familiar with it [4], and various training models are essential for consolidating the use of this surgery [31, 32].

Percutaneous renal access under fluoroscopic control

In general, all patients undergoing any percutaneous renal procedure are given a general anesthetic. Then the patient is placed in a lithotomy position for cystoscopy, with insertion of a 6F open-end ureteral catheter under fluoroscopy guidance.

A retrograde urogram then delineates the ureteral anatomy, as well as the exact stone location, degree of hydronephrosis, and the image of the selected calyx in order to plan the approach to the collecting system if this is deemed necessary [33].

The rigid cystoscope is used to place a 0.038-inch Teflon-coated guidewire into the upper collecting system. When a tortuous area blocks the progress of the guidewire, a wire with a hydrophilic coating must be used. This wire is composed of an alloy core, a polyurethane jacket, and a thin hydrophilic polymer as the outermost layer. When in contact with fluid, the polymer binds water to create a lubricious coating with greatly diminished friction, avoiding excessive edema and creation of a false passage. When the guidewire is in position, the 6F catheter is advanced over it to the renal pelvis, and the endoscope is removed.

A 16F Foley catheter is inserted and attached to a drainage bag at the same time. Both catheters are tied with 2-0 silk to secure them in place. It is helpful to connect an empty syringe to the Luer lock adapter at the end of the ureteral catheter to prevent urine leakage.

The patient is positioned prone to allow posterior access. The patient is moved slowly and gently to allow the body to adjust to the position change. A foam rubber pillow is placed under the head to prevent it from being angulated excessively in relation to the trunk. The endotracheal tube is placed in the side slot of the foam pillow, making sure that the tube is unobstructed and free from kinks. To reduce resistance to breathing, the chest and abdomen are elevated on two foam rubber rolls that extend from the shoulder to the hip. Knee donuts padded with sheepskin inside the ring are positioned between the knees and the operating table to protect the bony prominences. A foam rubber roll is placed anterior to the ankles. The arms are flexed and secured on padded arm boards, and the elbows are protected with sheepskin pads. At this time, the 2-0 silk tie securing the two catheters together is cut and discarded. The intravenous extension tubing is connected to a 60-mL syringe containing 25% diatrizoate (Hypaque) solution, and the tubing is primed. The nurse removes the empty syringe from the ureteral catheter and attaches the syringe and tubing to the Luer lock adapter of the ureteral catheter.

Recently, several reports have been published of percutaneous renal surgery in the supine position [34, 35]. This has potential advantages over the prone position for PCNL but it has not been adopted by most urologists (see Chapter 10). The modified supine position preserves cardiovascular and ventilatory dynamics and allows better access to the respiratory tract. Additionally, the bowel slips away from the puncture area, lowering the risk of it being damaged. PCNL with the patient in a modified supine position may be considered for most patients, especially if concomitant ureteroscopy is planned [36].

The percutaneous nephrostomy is created via an upper, middle, or lower calyx. Thorough evaluation of the renal collecting system anatomy is essential prior to definitive percutaneous puncture for access tract creation. The information provided by preoperative helical CT is very valuable at the time of puncture under fluoroscopic control [37], as it identifies the most suitable place to set the path of the needle from the skin to inside the calyx that has been chosen for tapping. A CT scan can assess the presence of adjacent organs brought into the path of the needle. In this case, there is the option to change that path at the time of puncture under fluoroscopic control or to decide that percutaneous access is contraindicated.

When deciding where to make the puncture, areas of parenchyma should be considered that are thick enough to maintain a stable needle path and prevent subsequent development of a fistula. Also, it is desirable to identify those calyces for which surrounding thickness of parenchyma will promote their spontaneous closure of the puncture. Areas of kidney with an extremely thin parenchyma should be avoided.

Also, the information provided by helical CT will allow paths to be planned that avoid simple cysts, which sometimes are present in the renal parenchyma and are frequently not picked up on fluoroscopy.

The collecting system is opacified with direct injection through the ureteral catheter of contrast. A posterolateral transparenchymal puncture minimizes the chance of injury to the major renal vessels. The chosen posterior calyx is visualized with the C-arm fluoroscopy unit in the posteroanterior direction initially. The posterior calyces are positioned 20° posteriorly to the frontal plane of the kidney in most right kidneys, and 70° posterior to the frontal plane of the kidney in most left kidneys. In a normally rotated kidney, the frontal plane of the kidney is 30° posterior to the coronal plane of the body.

Percutaneous access to the upper urinary tract through a calyx must meet five conditions that guarantee safe access and avoid complications: access is performed from a posterolateral position, through the renal parenchyma, toward the center of the calyx posterolaterally, and toward the center of the renal pelvis, and as a result of these four conditions, the trajectory does not damage any major blood vessels.

There are two primary methods used to gain fluoroscopy-guided percutaneous renal access: the ''bullseye'' technique and triangulation [38, 39]. Both techniques need a target, most commonly generated by opacification of the collecting system with iodinated contrast that is administered retrograde via a ureteral catheter. A calyceal entry point is selected to avoid the larger vascular structures that are found at the level of the infundibulum.

As with most percutaneous access techniques, the bullseye technique requires fluoroscopy to monitor and guide the procedure. To this end a ureteral catheter is placed and the patient is positioned as described above. With the C-arm in the 30° position, an 18G diamond tip access needle is positioned, so that the targeted calyx, needle tip, and needle hub are in line with the image intensifier, giving a bullseye effect on the monitor. In effect the surgeon is looking down the needle into the targeted calyx. The needle is advanced in 1–2-cm increments using a hemostat to minimize radiation exposure to the surgeon. Continuous fluoroscopic monitoring is performed to ensure that the needle maintains its proper trajectory. Needle depth is ascertained by rotating the C-arm to a vertical orientation. If the needle is aligned with the calyx in this view, the urologist should be able to aspirate urine from the collecting system, confirming proper positioning.

The triangulation technique is based on simple geometric principles and is guided by biplanar fluoroscopy; one plane is anteroposterior to the line of puncture and the other is oblique. The anteroposterior view may be considered to be in a plane parallel to the axis of puncture and is used to monitor mediolateral (left–right) adjustments. The oblique view gives information regarding depth to the site of puncture and is used to monitor needle adjustments in the cephalad–caudad (up–down) orientation.

The tip of the needle is oriented towards the calyx to be punctured in both the anteroposterior and oblique planes. Left–right adjustments are limited to the anteroposterior view only, and cephalad–caudad adjustments are limited to the oblique view. When making adjustments in the mediolateral axis, care should be taken not to inadvertently move the needle in the cephalad–caudad axis, and vice versa. In most cases, it is helpful for the surgeon to rest their arm on the patient during the access part of the procedure, as this minimizes unintended drifting of the needle away from the targeted axis and also provides additional needle stabilization.

To decrease the radiation exposure to the surgeon's hands, the C-arm should be oriented with the image intensifier angled toward the head of the patient. Whenever possible, the iris of the fluoroscope should be kept as small as possible, to further minimize stray radiation exposure. Once the needle is aligned with the targeted calyx in both the mediolateral and cephalad–caudad orientations, it is advanced with continuous fluoroscopy. The needle should always be advanced in the oblique view, which will allow for the assessment of the depth of the needle's penetration. It is helpful for the anesthesiologist to hold the patient's respirations while the needle is being advanced, to avoid having to "hit a moving target", as well as to minimize the risk of an inadvertent transthoracic puncture. After advancing the needle several centimeters in the oblique view, the anteroposterior view should be examined to confirm that the mediolateral trajectory of the needle is still properly aligned to the target. If necessary, the needle trajectory can be readjusted to maintain proper targeting. Again, it is critical not to alter the access needle's orientation in one plane while making adjustments in the other plane, particularly when advancing the needle.

Several groups have reported refinements in techniques, incorporating elements of the bullseye and triangulation methods, proposing new approaches, describing adjuncts, and using new technology. Mues *et al*. described a geometric model to create a plane of coincidence between the C-arm and the needle, each at the same angle of 20–30° from the targeted calyx, but in opposite directions [40]. For lower pole access, the C-arm is rotated cranially 30° from the vertical plane, and a needle is advanced from a position distal to the calyx, rotated caudally 30° from the vertical plane. For mid-renal and upper pole calyceal access, the C-arm is rotated 20° away from the surgeon, and a needle is advanced from a position lateral to the calyx, at an angle of 20° toward the surgeon from the vertical plane. In either case, the C-arm remains fixed, and the needle is advanced until the point of coincidence between the calyx and the needle tip is reached. This technique purportedly eliminates the need for C-arm rotation, thus potentially reducing C-arm manipulation and fluoroscopic exposure time. This technique, however, requires a plumb, protractor, and ruler to calculate and confirm the necessary measurements.

Another recently proposed modification by Sharma and Sharma represents a hybrid of the bullseye and triangulation techniques [41]. The posterior calyx that provides the best access for stone clearance is selected. The initial puncture needle is held at this point. The needle with its overlying hub in the same line as the calyx creates a bullseye effect on the C-arm monitor. The site on the skin corresponding to the target calyx is thus determined, and its position is marked with a hemostat as point A (see Video 13.1). We place an intramuscular needle at this point instead of a hemostat. Then, under direct vision, the needle is placed vertically and the puncture is made at this point in the subcutaneous cellular tissue at a depth of about 1 cm (Figure 13.1A). The visual control of the needle in the vertical position reduces fluoroscopic exposure to a few seconds. Subsequently, a brief fluoroscopic exposure is used to check the position of the needle and it is shown on the screen as a point. The trajectory of the line of puncture of the needle into the dorsal area represents an imaginary line through the selected calyx in the anteroposterior direction. However, this trajectory does not meet all five requirements for optimum puncture, described above, as the needle is not directed toward the center of the renal pelvis.

The C-arm is then angled toward the surgeon, 30° from the vertical in the axial plane. With the ventilation suspended in end expiration, the second puncture needle is held over the targeted calyx in such a way that the needle with its hub is in the same line with the calyx, which leads to a bullseye effect on the C-arm. This particular point on the skin is punctured with an intramuscular needle and is taken as point B (Figure 13.1B) (see Video 13.2). This position represents an imaginary line that is projected onto the center of the selected calyx. Again, all five requirements for safe renal puncture are not met because the trajectory is not toward the center of the renal pelvis. This position is checked in relation to the 12th rib. Visually observing the trajectory of the two small needles placed in the lumbar area, the intersection of two lines coincides with the desired calyx.

The distance between the two needles is measured. (Figure 13.2A). The C-arm is then brought back to its vertical position. Now the line of puncture is determined in alignment with the infundibulum from point A. Along this point line, the point B1 is marked. The

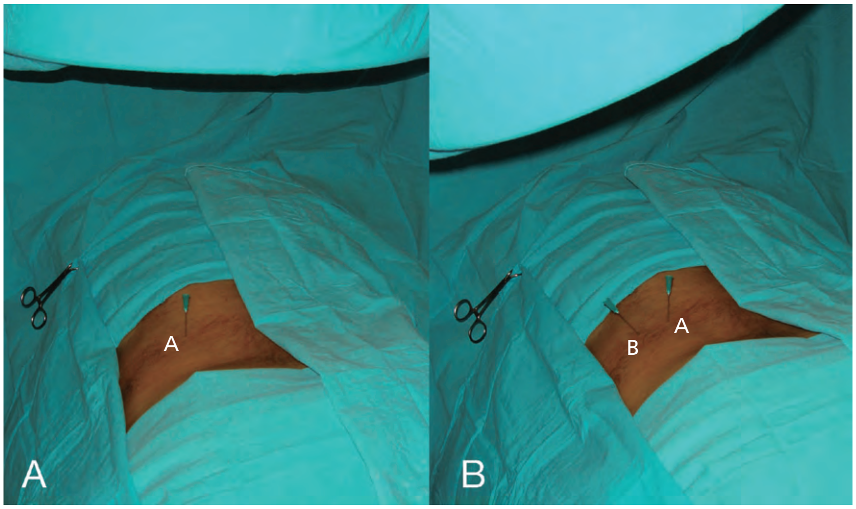

Figure 13.1 (A) The intramuscular needle with its overlying hub in the same line as the calyx creates a bullseye effect on the C-arm monitor. The needle is placed upright and puncture is done at this point at a depth of about 1 cm in the subcutaneous cellular tissue. (B) The C-arm is angled 30° toward the surgeon. The second needle is held over the targeted calyx in such a way that the needle with its hub is in the same line with the calyx, which leads to a bullseye effect on the C-arm.

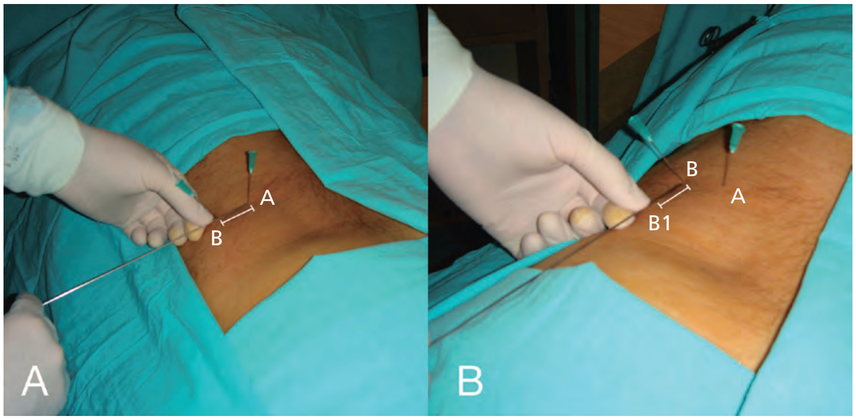

Figure 13.2 (A) Distance between the two needles is measured. (points A and B). (B) B1 is the point where the skin will be punctured for renal access. The distance between points A and B1 is equal to or greater than the distance between the intramuscular needles.

distance between points A and B1 is equal to or greater than the distance between the intramuscular needles (points A and B) (Figure 13.2B). The point B1 is the point where the skin is punctured for renal access. A small incision is then made at point B1 and the 18G needle is introduced for 1–1.5 cm (Figure 13.3). Now, with the C-arm in the 90° vertical position (i.e. parallel to the line of puncture), the mediolateral (right to left) adjustments are made. Then the C-arm is tilted toward the head of the patient by 30° and adjustments are made in the cephalad and caudal orientation of the line of puncture. The needle orientation is maintained in one plane while making adjustments in the other plane. With the C-arm in the oblique orientation, the needle is advanced with ventilation suspended in full expiration. Under fluoroscopic control and from this position, the 18G needle is advanced towards the point of intersection of the two lines that project both intramuscular needles to reach the selected calyx (see Video 10.3). This is the ideal path and the only one that meets the five requirements described above of a safe percutaneous renal puncture.

When the tip of the needle appears fluoroscopically to be within the collecting system, the needle trocar is removed, leaving only the needle cannula in place, and a small amount of urine is aspirated to confirm the needle's intraluminal position.

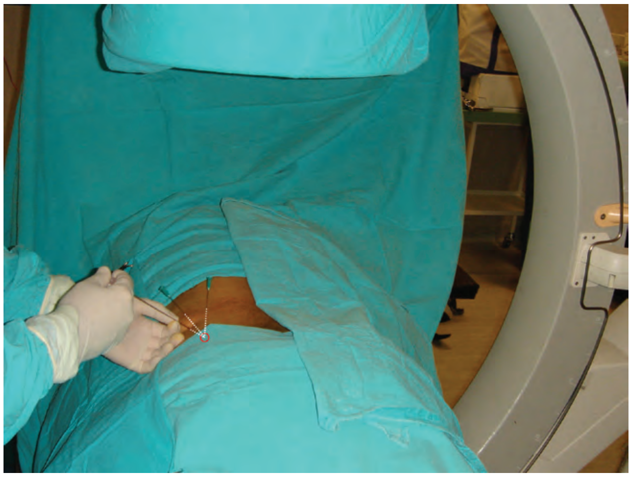

Figure 13.3 The intersection of the two lines of small needles placed in the lumbar area coincides with the desired calyx. The 18G needle is advanced under fluoroscopic control towards the point of intersection of the lines that project both intramuscular needles in order to reach the selected calyx.

Definitive puncture of the renal collecting system with an 18G diamond needle permits the immediate introduction of a 0.038-inch guidewire into the collecting system. The rigidity of this needle is advantageous for accurately directing the needle diamond tip as it is advanced through the fascial planes.

If at the point of withdrawing the trocar of the needle spontaneous output of urine has not been observed, it is advisable gently to try to introduce a hydrophilic guidewire, observing the advancement of the guidewire under fluoroscopy. Typically, it moves into the cavity of the calyx and progresses towards the renal pelvis. If for some reason the guidewire does not easily advance, it is advisable to inject an additional volume of contrast through the initially placed ureteral catheter with the intention of filling the calyx cavity and thereby facilitating the progression of the hydrophilic guidewire.

If no urine exits from the 18G needle, it is not advisable to inject contrast through the needle, since contrast can extravasate, creating a lake of radio-opaque material and making it difficult to visualize the shape of the kidney cavities. Should this occur, the procedure must either be abandoned and returned to at another time, or the urologist must wait until there has been adequate absorption of the contrast material.

In situations where the volume of the stone occupies the entire volume of the calyx selected to be punctured, the needle is advanced until there is the tactile sensation of the needle tip touching the hard surface of the stone. In this situation the tip of the trocar of the needle is in contact with the stone but the cannula of the needle is at a distance of 1–2 mm from the surface of the stone. It is advisable to then move the cannula on the trocar toward the stone until contact with the surface of the stone is felt. Then the trocar needle is removed and the hydrophilic guidewire is gently inserted into the narrow space between the urothelium of the calyx and the surface of the stone. Sometimes this allows the advancement of the guidewire to the renal pelvis, but in other situations it is only possible to locate the guidewire in the punctured calyx and attempting otherwise is risky because of the short length of the guidewire in the upper urinary tract. The guidewire is advanced carefully across the calyceal infundibulum. A 1-cm skin incision is made around the needle with a No. 10 blade, and the needle is removed. Then, in order to enlarge the defect in the lumbar fascia, a fascial incision needle can be used (No. 090070 Cook Urological). This instrument consists of an 18G needle fixed to a small, blunt, diamond-shaped blade that is passed over the puncture wire under fluoroscopic control, through the abdominal wall until it crosses the lumbar fascia. It is then withdrawn while gentle traction is placed on the puncture wire, and the tip of the blade is rotated 90° and then advanced again over the puncture wire in order to open the lumbar fascia more extensively. This action will facilitate the introduction of any of the available dilation systems.

Acute dilation of nephrostomy tracts can be performed with a variety of instruments. These instruments are inserted over a working guidewire. Because of the risk of perinephric guidewire kinking with loss of the nephrostomy tract and laceration of the renal parenchyma, all percutaneous dilator systems require fluoroscopic guidance [42–44].

The nephrostomy tract is dilated to 30F. In the serial dilation system, an 8F Teflon catheter is used as an obturator. Progressively larger dilators are then serially inserted over this guidewire and catheter combination. This additional obturator stiffness greatly reduces the risk of perinephric guidewire buckling.

With the access tract dilated, a working sheath is introduced into the collecting system under fluoroscopic guidance over the 30F dilator, which is then removed. The renal pelvis is examined nephroscopically to identify the obstructed segment of the ureteropelvic junction (UPJ) and locate the previously placed ureteral catheter. If necessary, either the ultrasonic probe or the grasping forceps are passed into the renal pelvis to clean out clots.

The catheter is grasped and brought out through the nephrostomy tract. A 0.038-inch super-stiff wire, which is a fixed core guidewire with an extra-stiff shaft and a flexible tip, is advanced through the catheter. A surgical assistant removes the ureteral catheter, leaving the guidewire in place at the urethral meatus (see Video 10.4). Once the UPJ has been bridged (i.e. the guidewire is in position from the flank through to the urethral meatus), the nephroscope is removed, and a hemostatic clamp is placed about 5 cm proximal to the distal end of the guidewire. It is pulled through the nephrostomy tract to position the clamp near the urethral meatus. This maneuver ensures the preservation of the nephrostomy tract, so that if the access route to the kidney is accidently lost, it is easily recovered by following the guidancedescribed above. Additionally, if for some reason the procedure has to be interrupted, placement of the nephroureteral stent will allow both drainage and subsequent easy access.

Special situations: multiple access

In the treatment of complex renal lithiasis with branches in multiple calyces, it is sometimes necessary to make multiple punctures through different calyces. The multiple punctures can all be made initially, or alternatively one puncture can be made, through which most of the stone is removed and, if necessary, additional punctures can then be made.

If the planned multiple punctures are made at the beginning of surgery, the injection of contrast through the initially placed ureteral catheter facilitates visualization of all calyces and the most suitable for punctures can be chosen in accordance with the silhouette of the stone. The injection of contrast distends the upper urinary tract and this facilitates insertion of the needles into the calyces.

In contrast, if multiple punctures are made in addition to establishing a unique initial nephrostomy tract, the calyceal distention of the cavities may be hampered by the leaking of contrast that is injected by a 6F ureteral catheter through the Amplatz sheath tract nephrostomy. In this situation it is advisable to place a Foley catheter and to inflate the balloon inside the Amplatz sheath to occlude its caliber. Thereafter it is possible to inject contrast either through the ureteral catheter placed at the beginning of surgery or the Foley catheter, and to place a clamp to prevent leakage of contrast from the distended renal cavity. This maintains the distention of the calyces, facilitating additional punctures under fluoroscopic control.

Liatsikos *et al*. have described the technique of a single subcostal skin incision with multiple angular punctures to approach the superior, middle, and lower pole of the kidney for the management of staghorn calculi [45]. Singla *et al.* have evaluated the safety and efficacy of an aggressive approach to staghorn calculi using multiple-tract PCNL, and reported a greater stone clearance rate without increasing the risk of significant complications [46].

Conclusions

Percutaneous endourologic procedures require an advanced level of skill. The techniques used should be understood by those treating patients with complex renal stone disease to improve their ability to manage these often challenging clinical problems. The bullseye and triangulation methods are the most commonly used approaches, but refinements in technique and applications of new technology offer the potential for improved access with reduced patient and surgeon morbidity. Percutaneous puncture, tract dilation, and antegrade nephrostomy sheath placement into the desired calyx can be achieved rapidly and with precision when fluoroscopy is adequately used. For this reason and for patient comfort, access is best achieved in the operating room by the urologist, even in special situations like staghorn stones requiring multiple or supracostal accesses, calyceal diverticulum, and horseshoe kidneys.

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CHAPTER 14

Computed Tomography for Percutaneous Renal Access

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Introduction

Percutaneous nephrolithotomy (PCNL) requires a combination of preoperative planning, optimal percutaneous access, successful intrarenal navigation, and intracorporeal lithotripsy. The quality of radiologic information displayed to the surgeon is therefore crucial. An understanding of the extent of the stone burden and its relationship to the pelvicalyceal (PC) system should be demonstrated in order to optimize percutaneous access. The well-planned track should allow unhindered endoscopic navigation and maximize stone clearance with minimal morbidity [1]. The exact relationship with other operative landmarks such as the ribs and intra-abdominal organs, especially the colon, also has to be established for safe access.

In this chapter, we cover the role of computed tomography (CT) for percutaneous renal access. Multidetector row CT (MDCT) has revolutionized the radiologic evaluation of urinary tract disease [2]. Dedicated unenhanced and enhanced CT has now replaced ultrasound or contrast radiography for the diagnosis of calculi [3]. When applied to percutaneous renal access for stone surgery, CT has further advantages, such as identifying abnormal visceral anatomy or examining the relationship between pleura and access site. It can be used for planning access, guiding access, and in postprocedural follow-up. Each of these is further discussed, and in particular the technique for gaining percutaneous access using CT is described.

Percutaneous access planning for percutaneous nephrolithotomy

A detailed knowledge of calyceal and infundibular anatomy, as well as renal rotation, is mandatory for the successful percutaneous removal of renal stones. Knowledge of the intrarenal anatomy helps the endourologist choose the appropriate procedure for each patient. A posterior calyx is the most appropriate for percutaneous access; however, the position of the anterior or posterior calyces in relation to the kidney margin is not predictable. Ideally, access during PCNL should be through a calyceal fornix to reduce the risk of injury to interlobar vessels. With the patient in the prone position, the posterior calyces are more amenable to direct puncture. An anterior calyx could be entered, but this increases the risk of bleeding as the line of puncture may traverse the infundibulum [4]. Another hindrance of anterior punctures is that it can lead to difficulties in navigating the rest of the collecting system. The chosen point of entry must not only be safe, but should permit maximal inspection of the collecting system, in order to obtain full stone clearance.

Imaging

Determining which calyces are anterior or posterior using common radiologic methods, including oblique and lateral views, can be difficult. The intravenous urogram (IVU) had traditionally been used as the standard imaging investigation prior to PCNL; however, it is limited in that it produces a two-dimensional image of a complex and variant structure such as the PC system. Any three-dimensional (3D) information, such as the branching and direction of the calyces, is assumed. Ultrasound, although having advantages of being radiation free and providing realtime images is poor at detecting small stones and cannot reliably depict the anatomy of the nondistended collecting system. Orientation is also difficult and the ramifications of the

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intracalyceal anatomy cannot be readily grasped from static ultrasound images. Currently, ultrasound is of limited value for planning PCNL, although it is of undoubted value for directing the needle for percutaneous access. Although basic 3D modeling is available on more recent machines, the quality still lags behind CT. This may change in future and PCNL planning on sonography may become feasible.

Computed tomography for planning percutaneous renal access

In comparison, CT can provide a wealth of 3D anatomic detail such that now it is the primary planning tool for PCNL. MDCT is even better than helical CT for visualizing the collecting system due to its thinner slice collimation and virtual elimination of motion artifact [2]. Currently, CT protocols for planning PCNL consist of either noncontrast or contrast-enhanced acquisitions of the collecting system, with or without 3D reconstruction.

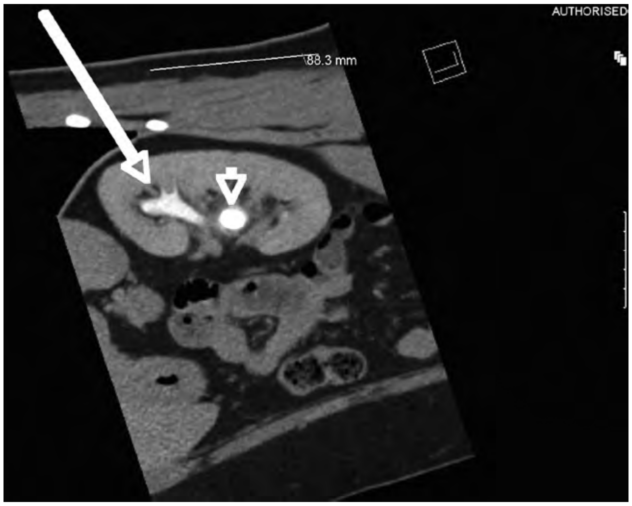

Figure 14.1 Sagittal reconstruction of a CT pyelogram study carried out to plan percutaneous nephrolithotomy access. Upper pole access (long arrow) would transgress the pleura and lung. Sagittal reconstructions are best for studying the relation between the thorax and upper renal pole (small arrow points to a pelvic calculus).

Noncontrast CT

Wickham *et al*. identified early on the advantages of noncontrast CT (NCCT) prior to renal stone surgery [5]. These included localization of peripheral stones to anterior or posterior calyces, determination of the direction of calyceal extensions of staghorn calculi, evaluation of the thickness of parenchyma overlying calculi, and visualization of low radiodensity stones poorly seen on plain radiographs. Contrast monoplanar radiography has traditionally been the standard for planning PCNL because the configuration of the collecting system cannot be established on NCCT. In comparison, the greatest strength of NCCT lies in its ability to detect even the tiniest calculi and any aberrant anatomy, especially the relationship of the kidney to the bowel and adjacent viscera.

Colonic perforation during PCNL has an incidence of 0.2–0.8%, with the left side at greater risk, especially during lower pole punctures [6]. NCCT can be used to determine the relationship between the colon and kidney, and should be routinely considered in patients with renal fusion anomalies, due to the high incidence of retrorenal colon [7]. Patients with a history of previous renal surgery, chronic colonic distention, spinal cord injury, and myelomeningocele are also more likely to have a retrorenal colon [6]. Likewise the ability to demonstrate the peritoneal reflections and overlying bowel has made NCCT the standard tool when planning access in the transplant [8] or ectopic kidney [9].

MDCT also allows image reconstruction with concomitant analysis of surrounding structures for access planning. This has limitations, in that the collecting system is not visualized and the exact position of the stones is assumed. But studies in the prone and supine positions, with sagittal reconstructions, have evaluated the risk of pleural injury during access (Figure 14.1). In patients prone and in maximal expiration, an intercostal approach between the 11th and 12th ribs would be expected to puncture the left lung in 14% and the right lung in 29% [10]. The same study demonstrated the risk of pleural injury via a supra-12th compared to a supra-11th rib approach was lower if access was in maximal expiration. In contrast, the risk of pleural injury from an upper pole supra-11th access was unaffected by the phase of respiration and prohibitively high [10].

A novel method to predict the success of fluoroscopically-guided superior pole access through an infracostal versus supracostal approach has also been described using axial NCCT [11]. CT measurements from skin to stone and stone to the first rib-free slice were used to calculate the angle required for the fluoroscopic C-arm to rotate from a supracostal to infracostal approach. In this study, an angle greater than 30° predicted failure of fluoroscopic access through a subcostal approach with a positive and negative predictive value of 100% and 76.4%, respectively.

More recent NCCT studies for planning percutaneous renal access have used 3D reconstruction techniques such as multiplanar reformatting (MPR). Using this method, any plane within the scanned volume can be recreated. One study using MPR for assessing lower pole access found that axial images overestimated the risk of colonic injury in comparison to oblique parasagittal reformations [12]. MPR has also been used to determine extra/transpleural percutaneous upper pole access in both phases of prone respiration [13]. Using this technique, unsafe or failed access was predicted, necessitating a different approach to management in some patients. We routinely obtain unenhanced prone MPR reconstructions to determine the risk of visceral or pleural injury when planning percutaneous access.

Noncontrast 3D CT reconstruction of the staghorn calculus for planning access has also been evaluated [14–16]. In selected cases, 3D CT reconstruction of the renal stone can help determine access site and intraoperative orientation [14]. In one study, the access site was altered in a third of patients to what would have been adopted if the corresponding IVU had been used [15]. However, not all studies have concurred on the benefits of this method for access planning [16]. This may be a reflection of the limited surgical road map gained from reconstructing calculi without visualizing their location within the collecting system.

CT urography and 3D reconstruction

In contemporary practice, management of urinary tract stones relies mainly, and in some places solely, on unenhanced CT as its diagnostic accuracy is nearly perfect, but it provides no information about the PC anatomy for planning renal access. A well-chosen track is the key to successful PCNL and for this preoperative imaging should clearly demonstrate the PC system and the distribution of all relevant calculi, warn against the possibility of parallel stone-bearing calyces, and demonstrate the orientation and tightness of narrowed calyces or the neck of a calyceal diverticulum. In the case of multiple calculi or a large staghorn calculus, imaging should show the best route of access to ensure complete stone clearance. An IVU will suffice but with its anatomic and spatial accuracy, 3D reconstruction of the collecting system on contrast-enhanced CT can be more informative.

Initial studies of 3D CT for PCNL were of limited value for planning access as the stone remained indistinguishable from the contrast [17]. This limitation has now been addressed with MDCT and improvements in the CT urography (CTU) technique. In a study of 10 patients with renal calculi, 3D reformatted CTU images helped identify two patients who were unsuitable for PCNL due to challenging stone position on 3D calyceal anatomy [18]. In those patients undergoing PCNL, 3D CTU helped select the percutaneous access site. 3D CTU has also been used for planning complex access, such as in the horseshoe kidney [19]. In this particular case, a rotating 360° volume-rendered (VR) movie loop of the PC system and stone was used for planning access. VR loops make it easier to grasp spatial relationships of the calyceal and stone anatomy, and provide a clear appreciation of angle of entry along with its relationship to the ribs. These reconstructions can be uploaded onto networked computers for review in the operating room during surgery [19].

The ability of preoperative 3D CT to help plan complex PCNL has also been studied by Radecka *et al*. [20]. Plastic biomodels were created from 3D reconstructions using 16-slice MDCT. Based on subjective criteria, the 3D biomodels helped determine access points, angles of entry, and endoscopic route. However, a drawback of this technique is that unenhanced and enhanced reconstructions had to be superimposed to determine stone location within the PC system.

3D CT pyelography

For reliable 3D CT planning of renal stone surgery some requirements need to be fulfilled. First, a technique for 3D reconstruction of the PC system has to be defined which is reproducible, easy to use, and provides rapid visual appreciation of spatial and anatomic relationships. All the calyces, calyceal orientation, and angles need to be faithfully recreated. Second, for clear stone and calyceal visualization the density of the contrast in the PC system should be sufficiently high to demonstrate all the calyces but without obscuring the stone. Contrast should also be evenly distributed as dense pools may result in artifact or simulate small calculi. Stone edge should be clearly demarcated against the contrast for accurate size measurement. Lastly, the surgeon should be able to choose an appropriate reconstruction method from the different formats available to provide the necessary information for treatment planning.

The accuracy of a focused 3D CT pyelography protocol for renal calculi depiction for PCNL access planning has now been assessed [21]. In this study of 20 patients undergoing PCNL, prone 3D CT pyelography accurately demonstrated stone position and spatial relationships of the collecting system. Maximum intensity projection (MIP) reconstructions were best for calculus depiction whilst VR studies were best for collecting system anatomy. 3D CT pyelography was able to demonstrate the presence of parallel stone-bearing calyces, and display calyceal orientation and the tightness of narrowed calyces or the neck of a calyceal diverticulum [21]. The radiation burden of this 3D CT pyelography protocol (mean estimated dose 3.2 mSv) was considerably lower than that with a standard CTU protocol.

Increasingly patients with renal calculi are being diagnosed after an initial CTU investigation. Table 14.1

Table 14.1 Acquisition factors when planning percutaneous renal access using computed tomography.

Factors	Suggested option	Value in percutaneous access
Patient position	Prone	Replicates patient position for percutaneous nephrolithotomy Better assessment of bleeding and pleural injury risk
Respiration phase	Maximal expiration	Less risk of pleural injury, especially if supra-12th rib access
Noncontrast CT	Axial CT	Essential in transplant or ectopic kidney Can predict success of subcostal fluoroscopic access
	Multiplanar reformation	Assesses risk of pleura or bowel injury
CT urography/pyelography	Maximum intensity projection reconstruction	Depicts calculi in pelvicalyceal (PC) system Easy to produce
	Volume rendered reconstruction	Depicts PC anatomy orientation and tightness of calyces Helps choose access site and intrarenal endoscopic route

summarizes the factors to consider when planning percutaneous renal access using CT. Currently, 3D reconstructions are routinely obtained by 40% of uroradiologists [22]. We recommend endourologists discuss their CT reconstruction requirements with their radiologic colleagues, in order to optimize preoperative imaging and information. Figures 14.2–14.4 illustrate cases of access planning using 3D CT pyelography. An example of a 3D CT pyelography protocol for planning percutaneous renal access is provided in Table 14.2.

CT for gaining percutaneous renal access

Biplanar fluoroscopy and ultrasound, either alone or in conjunction with fluoroscopy, are the most commonly used imaging methods for gaining percutaneous renal access for PCNL [23, 24]. However, in certain scenarios, CT-guided access may be the only viable option as it provides precise cross-sectional imaging through which needle puncture of the collecting system can be achieved. This technique was first reported by Haaga *et al*. in 1977 [25].

Indications

Indications for CT-guided access include anatomic difficulties, such as spinal dysraphism [26], morbid obesity, abnormal visceral anatomy (retrorenal colon or spleen) [26], abnormal urinary tract anatomy (urinary diversion) [27], abnormal renal anatomy (multiple cysts, angiomyolipoma) [28], ectopic/transplant kidney, and failed access using standard fluoroscopy/ultrasound. The latter may occur in nondilated systems where definition of the collecting system is not feasible using retrograde (due to ureteric stricture) or intravenous contrast (due to obstruction/renal failure) administration. CT-guided access has also been used to undertake diagnostic antegrade pyelography as an alternative technique to CTU in patients with urinary tract obstruction [29].

Technique

CT-guided percutaneous renal access may be undertaken in an interventional CT suite using CT fluoroscopy [30] or using a hybrid unit that combines CT with standard fluoroscopy [31]. It can also be performed in a standard CT unit, with intermittent scans taken with the operator outside the room [32]. This last method avoids radiation exposure to the clinician but is slower. Some investigators have also used laser guidance systems to facilitate needle entry [30]. Access is obtained with the patient prone or supine–oblique. The latter can be advantageous for patients with respiratory difficulties.

A scout tomogram is initially registered to help localize scans to the renal region. A noncontrast acquisition of the abdomen is obtained and the kidneys assessed for dilation, presence of renal masses, and relative position in relation to colon, spleen, liver, and diaphragm. The collecting system should be easily discernible if dilated. If not, intravenous administration of contrast will delineate any nondilated system.

A suitable calyx for entry is identified following the principle that the safest, most direct route is through the fornix of a posterior-facing calyx. This reduces the risk of arterial hemorrhage. In comparison, infundibular or pelvic entry [33] risks transgressing the more medially placed larger arterial divisions, especially the upper pole segmental branch which courses posterior to the pelvis and upper pole infundibulum. Skin markers may be placed over the selected entry site and a further localizing scan helps reposition the marker, such that it accurately overlies the target calyx in the transverse plane [25]. Localizing scans limited to the area of interest reduce the radiation exposure. Once confirmed with the

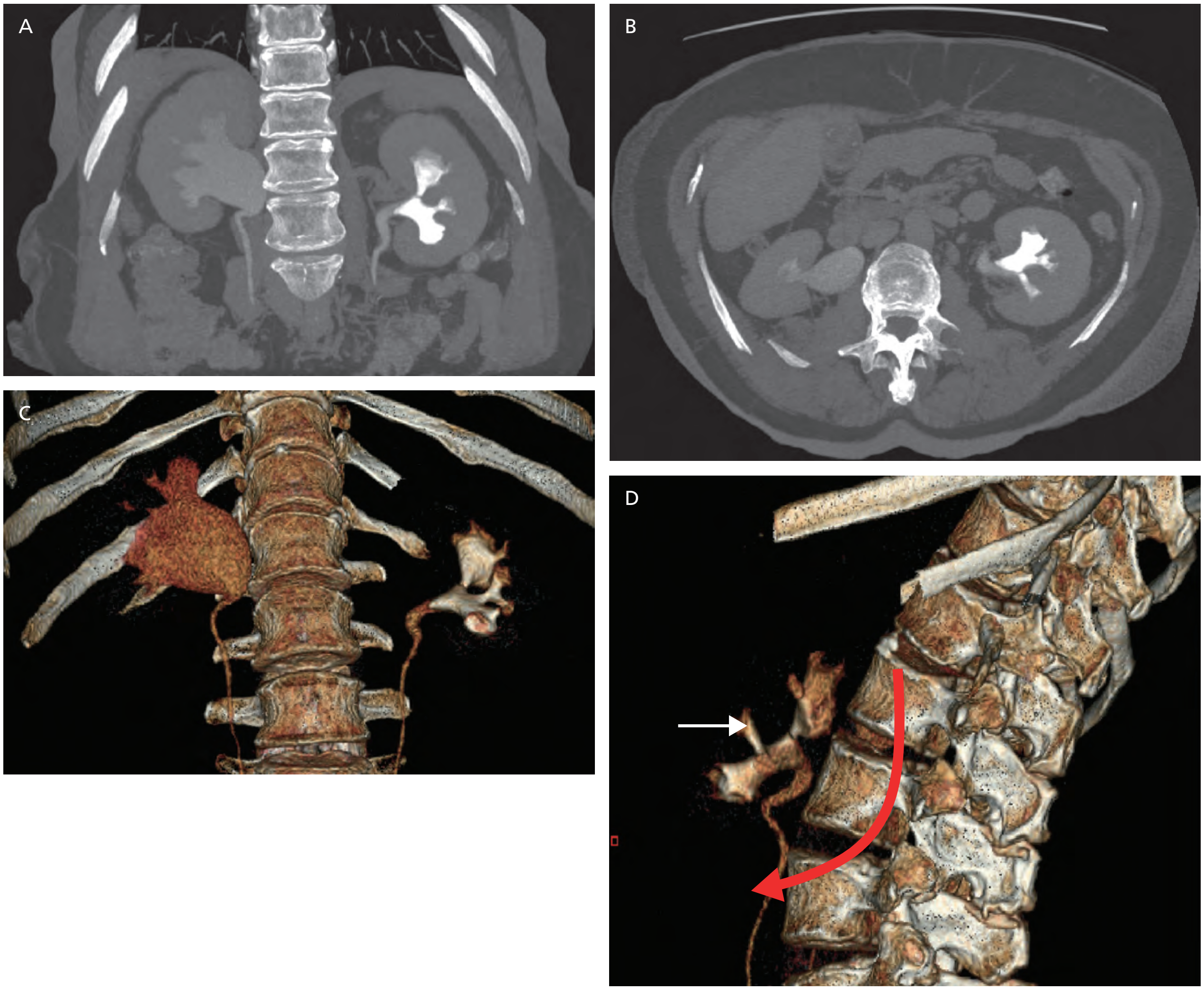

Figure 14.2 (A) Coronal and (B) axial maximum intensity projection (MIP) and (C, D) volume rendered (VR) CT reconstructions of a complete left-sided struvite staghorn calculus in a 77-year-old woman. Although the axial and coronal studies demonstrate the stone, planning of renal access is more confident with the VR studies. The lateral view (D) is taken from the movie loop and shows that the kidney has "flopped" posteriorly. Upper pole access would allow easy navigation from the upper to the lower pole (red arrow) via the renal pelvis but the lateral (interpolar) calyx (white arrow) lies at an acute angle. In planning, this may indicate a second direct puncture for stone clearance but as it is a nondependent calyx, the patient could have auxiliary shock-wave lithotripsy for retained fragments in this calyx.

transverse alignment for needle entry, the skin is sterilized and draped. After infiltration of local anesthesia, a 15-cm 18G needle with sheath (e.g. Kellett needle, Rocket Medical, Watford, Herts, UK) is advanced subcutaneously towards the target calyx. A further localizing scan with the needle in place helps finer adjustment of the needle trajectory. Based on this scan the trajectory of the needle is altered and either advanced or withdrawn until urine is obtained. Aspiration whilst withdrawing the needle may help.

Sometimes two or three localizing scans are needed for the needle to gain access to the collecting system. Often it is only necessary to advance or withdraw the needle a few millimeters to hit the target calyx. Once urine is obtained, a repeat scan confirms the position of the needle tip in the collecting system. The needle stylet is then removed and a guidewire is inserted through the plastic sheath into the collecting system. The sheath is removed and a small skin incision allows advancement of sequential dilators for tract dilation. Tract dilation may proceed using CT only, or in a standard manner with fluoroscopy and antegrade instillation of contrast. A nephrostomy tube is placed in the PC system (size 8–10F) and a further scan confirms its placement as well as excluding immediate local complications. The nephrostomy tube is sutured to the skin and the patient transferred for subsequent PCNL. Figure 14.5 demonstrates a case where CT guidance was used to access the PC system.

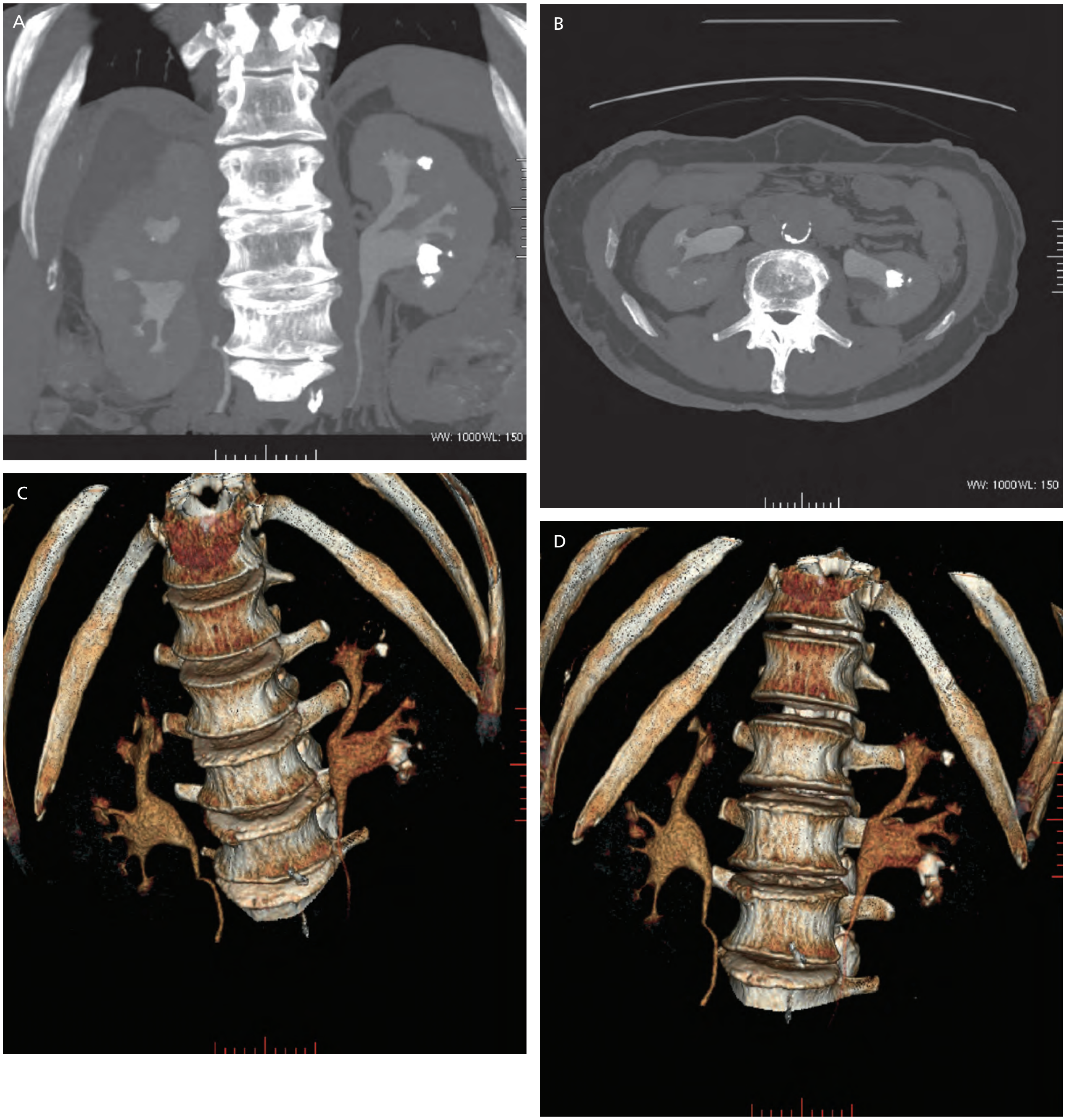

Figure 14.3 (A) Coronal and (B) axial maximum intensity projection (MIP) and (C, D) volume rendered (VR) CT reconstructions of mixed calcium stones in multiple calyces of the left kidney in a 76-year-old man. The MIP studies demonstrate all calculi well but the spatial relationships of the collecting system are only fully appreciated with the VR reconstruction. The lower pole stones lie in a relatively anteriorly placed calyx. The lower pole infundibulum is wide, but the upper pole infundibulum is narrow, and the angle between the pelvis and upper pole infundibulum is relatively acute. Furthermore, the upper pole stone lies in a narrow, laterally orientated calyx. With this knowledge a lower pole track was made, the lower pole stones removed with a 24-Fr rigid nephroscope, and the upper pole calculus removed with a 12-Fr flexible nephroscope and a wire basket. Complete stone removal was achieved with a single puncture.

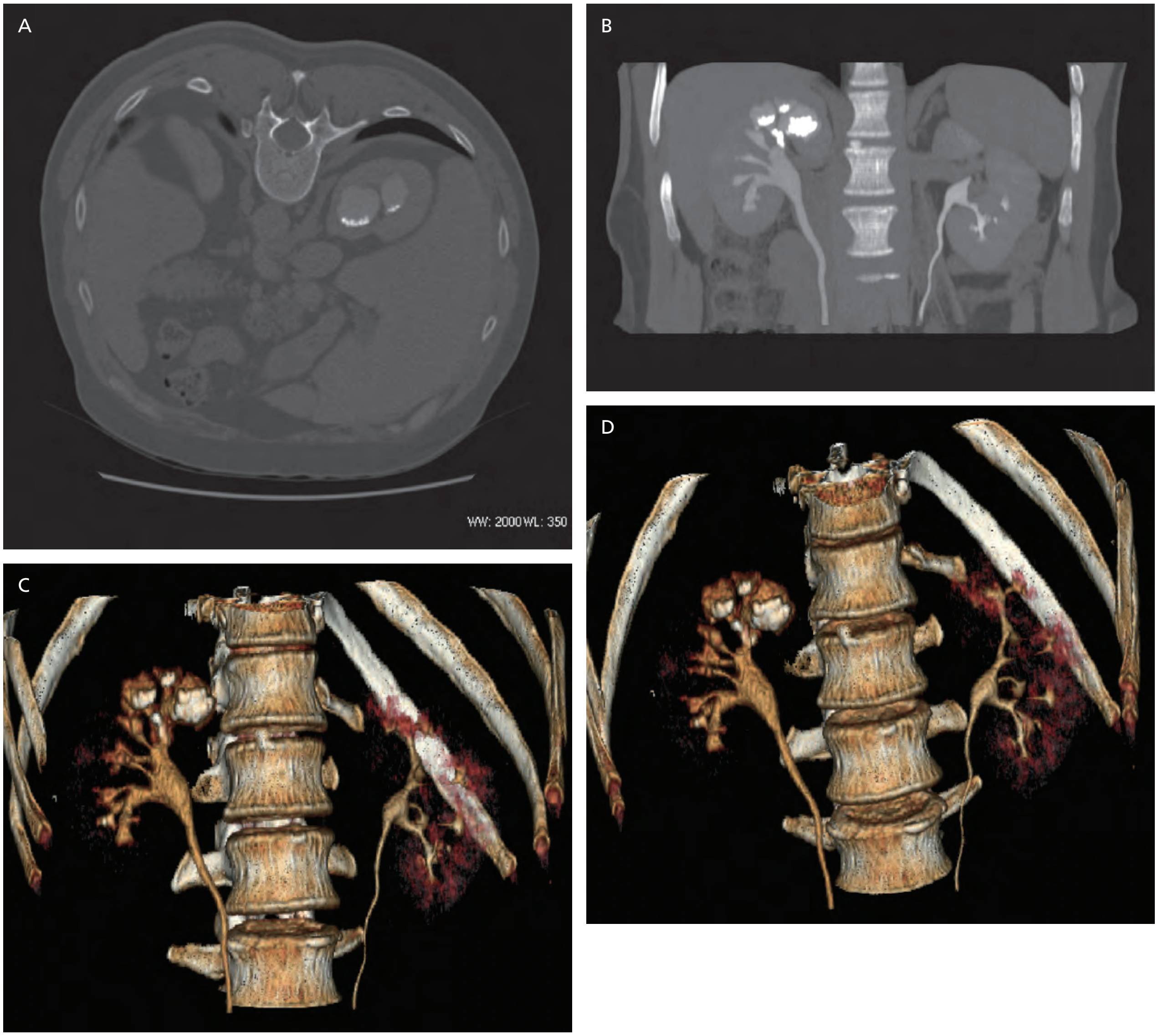

Figure 14.4 (A) Axial and (B) coronal maximum intensity projection (MIP) reconstructions and (C, D) volume rendered studies in a 67-year-old man with calcium oxalate stones in the right kidney. The obstructing fragment in the upper pole infundibulum is well seen on both the MIP or VR studies (arrow), but with the help of the VR studies, especially the movie loops, the most lateral of the stone-bearing calyces was chosen for track dilation.

Outcomes

Most studies of CT-guided access have evaluated nephrostomy tube placement for a variety of indications, including PCNL [29–32, 34, 35]. A summary of the results from large series is provided in Table 14.3. Failure of percutaneous access using CT guidance is rare and nearly all studies report 100% success rates [32–35]. Minor complications vary between 1% and 14%. However, even CT guidance does not eliminate the risk of pneumo/hydrothorax and other major complications, such as bleeding, requiring embolization [35]. Dilated PC systems are associated with a lower incidence of complications, procedural time, and need for repeat punctures [34]. In the series of six CT-guided punctures for PCNL by Matlaga *et al*. there were no access failures or complications [26]. The complete stone-free rate was 83%.

CT after percutaneous access

Following CT-guided percutaneous access an immediate scan can rule out significant procedural-related complications. Furthermore, CT can detect and correct malposition of the nephrostomy tube. Fluoroscopy in the presence of a renal pelvis perforation can lead to a

Table 14.2 3D CT pyelography protocol for planning percutaneous renal access and stone surgery [21].

*Data acquisition**

1. Administer 10 mg of intravenous furosemide
2. Acquire contiguous noncontrast supine scans of the abdomen, 2.5-mm slice thickness, concentrating on the renal region in breath hold
3. Combine 100 mL of iodinated contrast (e.g. Omnipaque 300 [iohexol 300 mg/mL]; Amersham Health, Bucks, UK) with 100 mL of 0.9% saline in a mechanical injector and inject intravenously into the patient at a rate of 3 ml/s
4. Start a timer on completion of the injection and apply abdominal compression using a compression belt
5. Rotate into prone position at 3 min, with compression maintained.
6. Obtain an enhanced abdomen/pelvic scanogram (scout image) for repositioning and acquire a pyelographic scan of the kidneys (using the same machine settings) at 8 min
7. Release the compression belt on completion of scanning
8. Reconstruct noncontrast and contrast-enhanced scans at 1.25-mm intervals with 50% overlap

Image processing

Maximum intensity projection (MIP): On the workstation, images of MIP reconstructions can be viewed and saved. Enhanced MIP studies are viewed at a window level of 1000 HU and width 150 HU. Slice thickness of coronal MIP is best set at 24.6 mm
Volume rendered (VR): VR models are produced by selecting preset thick-slab algorithms on the workstation. VR studies are reconstructed by adjusting the lower end of the voxel density threshold until the renal parenchyma is removed and the calyces seen without losing any calyceal detail (voxel density threshold usually between 115 and 135 HU)
VR movie loops: Loops can be formatted to different magnifications, resolutions, speeds, and angles of rotation. We recommend a 360° rotating loop centered on the spine displaying the pelvicalyceal system with the lower ribs, revolving in 2° increments at a resolution of 1024 × 1024 bit

*All scans taken with a 16 × 1 25 mm configuration, pitch table speed of 27.5 mm/rotation, 120 kVp and 150–360 mAs (automatic tube current adjustment).

"white out," making manipulation of the nephrostomy tube difficult. Using CT the nephrostomy tube can be repositioned in the PC system by withdrawing the tube at the skin surface by the same distance as that between the tip of the extruded pigtail catheter and the renal pelvis [36].

The superiority of CT in assessing location (intra/extra-renal) and size of residual fragments (RFs) following renal stone surgery is established [5, 37]. Unenhanced MDCT is the gold standard for detecting RF after PCNL [38]. In a prospective analysis of antegrade pyelography, plain radiography (KUB), and NCCT after PCNL, there was a threefold reduction in completely stone-free patients if CT was used to evaluate RF status at 1 month. RFs detected on CT that were "clear" on antegrade pyelography and KUB had a mean size of 7.6 mm in 42% of patients [39]. However, a more recent study comparing noncontrast MDCT with KUB and linear tomography found no statistically significant increase in sensitivity for opaque RF greater than 5 mm [40]. This has led to the concept of the "CT clinically insignificant RF" as being less than 5 mm [40]; but this is not yet an accepted threshold. Recent work by Margaret Pearle's group has demonstrated that RF greater than 2 mm on CT after PCNL is an independent predictor of future stone-related events [41].

Conclusions

The breathtaking precision of MDCT has enhanced the power of CT for planning percutaneous renal access and stone surgery. Noncontrast reformations may raise the possibility of access-related visceral injury, necessitating an alternative access site or treatment option. 3D CT pyelography can delineate the exact location of calculi in the PC system and so help identify the most appropriate entry point for maximum stone clearance. Axial CT can be used to gain access in difficult cases. Following PCNL, CT serves as an accurate method for determining local complications as well as helping in repositioning the dislodged nephrostomy tube. Finally, the status of RFs following PCNL is best determined on unenhanced CT.

CT subjects the patient to radiation exposure, which over a lifetime can be considerable. For surgical intervention such as PCNL, the benefits of CT planning outweigh the immediate radiation concerns. Improved stone clearance would also reduce subsequent imaging. We recommend judicious use of CT and paying particular attention to those at greater risk of radiation exposure (young people, women, recurrent stone formers, particularly cystinuria patients). With the increased complexity of modern imaging, a close working relationship between the urologist and radiologist within

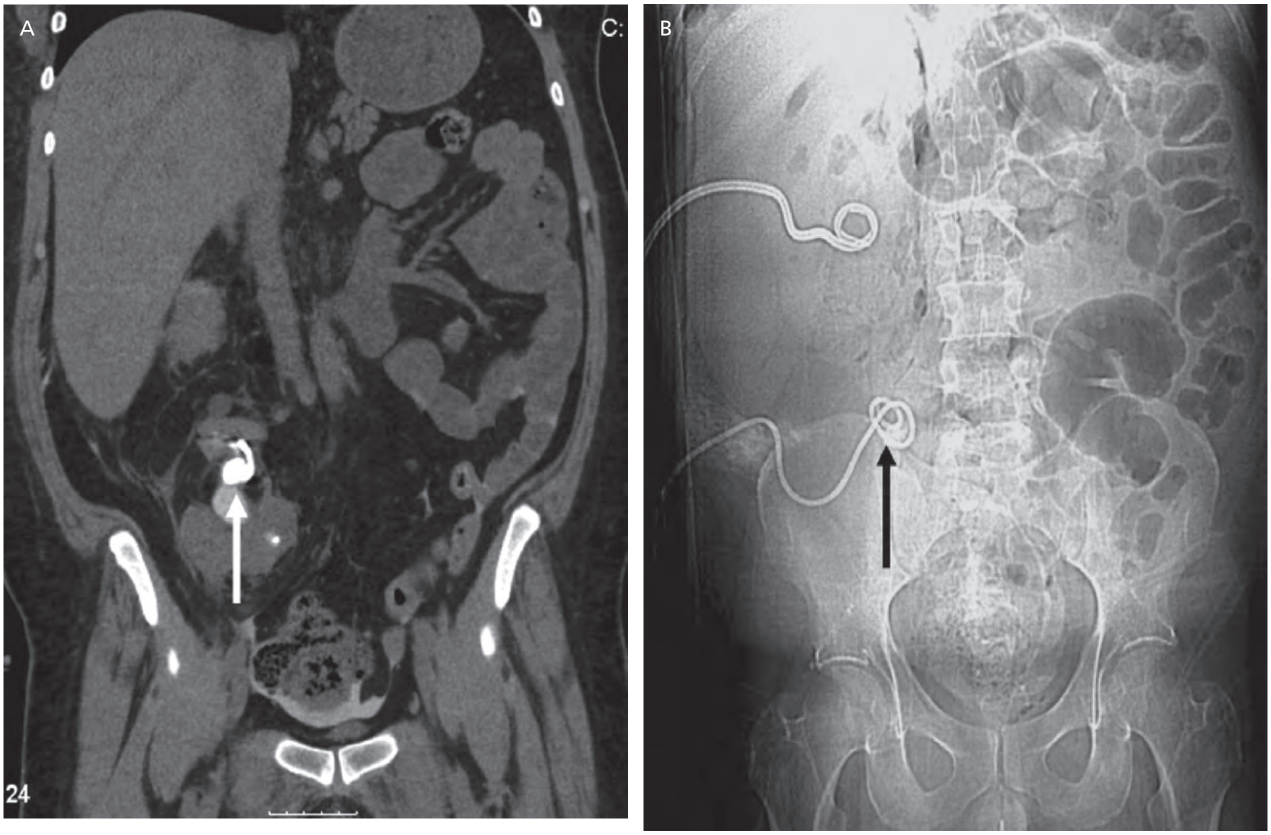

Figure 14.5 (A) Multiplanar reformatted (MPR) CT and (B) plain abdominal radiograph taken from a patient who presented with crossed fused ectopia and stones in both kidneys. The coronal CT image (A) shows a nephrostomy tube placed for access in the lower pole under CT guidance to avoid the peritoneum. The stone (arrow) is adjacent to the pigtail tip of the nephrostomy. The corresponding plain radiograph (B) shows the stone (arrow) (the stone in the orthotopic kidney has already been removed).

Table 14.3 Summary of results from CT-guided renal access studies.

Study	No. of procedures	Access failures (%)	No. of punctures	Procedural time	Complications
Le Maire *et al*. 2000 [30]	30	13	>One puncture 17%	Mean time 25 min; range 10–45	Retroperitoneal hematoma (3%), blood clot (3%), urine infection (7%), nephrostomy tube (NT) dislodgement (7%)
Barbaric *et al*. 1997 [31]	148	3	Two punctures11% Three punctures 7% Four punctures 3% Six punctures 1%	Not stated	Perinephric urine leak (5%), fever (2%), NT dislodgement (1%)
Thanos *et al*. 2006 [32]	258	0	Not stated	Range 15–50 min	Pain (14%), subcapsular hematoma (1%)
Radecka *et al*. [35]*	19	0	Not stated	Not stated	Pneumothorax (5%), bleeding requiring transfusion (5%), hydrothorax (10%), bleeding requiring embolization (5%)
Egilmez *et al*. 2007 [34]	1113	0	Two punctures 19% Three punctures 8%	Range 10–30 min	Perirenal hematoma (0.7%), frank hematuria (14%)

*Access obtained in patients undergoing PCNL only.

the endourology team allows for appropriate preoperative imaging for planning as well as for timely investigations in the management of complications.

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CHAPTER 15

Endoscopic Guidance for Percutaneous Renal Access

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Introduction

While the methods of percutaneous access into the renal collecting system have changed since its initial description by Fernström and Johansson in 1976, their goal to create safe and direct access into the collecting system have not [1]. This chapter will detail one of these methods, the approach combining endoscopy (or ureteroscopic) and percutaneous fluoroscopy. The combined approach was first described by Grasso *et al*. in 1995 for patients with complex stone burdens and nondilated collecting systems, and obese patients who had failed prior percutaneous access using only fluoroscopic guidance [2]. While initially viewed as a salvage technique to be used for complex cases, the combined ureteroscopic and percutaneous approach offers many potential advantages to enable complete stone clearance of large stones, while the possible disadvantages of increased operating time, inability to reach the desired calyx due to an obstructing stone, or difficulty with ureteral access are minimal. Table 15.1 lists some of the potential advantages of endoscopically-guided percutaneous renal access.

Technique

Operating room preparation

The operating room is set up to allow efficient maneuvering between the affected flank of the patient and the external genitalia while the patient is in the prone position. In order to do this, the large equipment necessary for the procedure are brought into the room around the patient. These are C-arm fluoroscopy, holmium laser, lithotripsy equipment, video towers, and suction canisters. Instrumentation necessary for the procedure is listed in Table 15.2.

Patient preparation

After the induction of endotracheal general anesthesia in the supine position, patients are positioned prone with their legs abducted approximately 35° on spreader bars to allow simultaneous access to the affected flank and to the external genitalia (Figure 15.1). Leg spreader bars that are compatible with fluoroscopy are used so as to not obscure any radiographic imaging near the pelvis. The patient is in the prone position with their perineum parallel to the end of the table and the table tilted so that the respective flank is parallel to the floor; this usually requires some head-down positioning of the patient. The affected flank, external genitalia, and perineum undergo sterile preparation and draping.

Retrograde ureteral access

After positioning and sterile draping of the patient, a flexible cystoscope equipped with a 0.035-inch floppy-tip hydrophilic nitinol guidewire is placed in the bladder and the guidewire is advanced up the ureter under fluoroscopic guidance (see Video 15.1). This is usually curled gently in an upper pole calyx. The cystoscope is then disassembled and removed, being careful not to disturb the position of the guidewire in the collecting

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Table 15.1 Potential advantages of ureteroscopic guided percutaneous renal access.

Direct visual confirmation of the target calyx
Minimal attempts at percutaneous needle localization (decreased fluoroscopy time)
Visual confirmation of percutaneous needle trocar placement
Ability to secure the percutaneous antegrade guidewire for through-and-through access
Visual confirmation of renal access tract creation
Simultaneous antegrade and retrograde lithotripsy for complex or large stone burdens in difficult antegrade access areas such as the upper middle calyx
Ability to clear stone fragments proximal to the renal access sheath in a retrograde fashion
Ability to clear stone fragments within the ureter
Increased success of supracostal percutaneous access
Decreased risk of pleural complications requiring treatment

system. After removal of the cystoscope, an 8/10F coaxial dilator sheath system (Boston Scientific Corporation, Natick, MA, USA) is advanced over the guidewire, again under fluoroscopic control, to the upper pole calyx. The 0.035-inch nitinol guidewire is removed and a retrograde pyelogram is performed via either the 8- or 10F coaxial dilator sheath system (the 10F has a Luer lock-type adapter). A 0.035-inch super-stiff guidewire is then inserted via the 8F sheath and curled in the upper pole calyx. The 8F sheath is removed from within the 10F sheath, keeping the super-stiff wire and larger sheath in place, and a 0.035-inch Bentson wire is advanced via the 10F sheath up into the upper pole calyx as well. The 10F sheath is withdrawn, and the Bentson guidewire is coiled and fixed to the drapes with a hemostat clamp; this guidewire will serve as the "safety" guidewire. The super-stiff wire will be the "working" guidewire.

A 12F Foley catheter is passed into the bladder to provide bladder drainage throughout the procedure. Next, a ureteral access sheath is selected with the appropriate length and diameter. Our rule of thumb is to initially select the middle sized ureteral access sheath (9–12F internal diameter and 11–14F outside diameter); the smaller sheath is usually only used if the 8/10F coaxial sheath was difficult to place or the medium access sheath was unsuccessful. Also, the ureteroscope diameter will determine the minimum sheath internal diameter needed. If the patient has had a stent previously, then we initially select a larger sheath (12–14F internal diameter and 14–16F outside diameter). The placement of the end of the ureteral access sheath determines the length selected. For renal access, the end of the access sheath rests 1–2 cm distal to the ureteropelvic junction (UPJ) so that the ureteroscope is able to make maximal deflections within the kidney. For females, we typically will use a shorter ureteral access sheath at 35 cm, and for males, a 55-cm ureteral access sheath. There are several lengths available for the access sheath, but these work for most of the patients we encounter. The ureteral access sheath is advanced over the "working" super-stiff wire under fluoroscopic guidance, making sure not to allow buckling of the access sheath or wire within the bladder.

Table 15.2 Instrument set for endoscopy-guided percutaneous renal access.

Operating room
Fluoroscopy-compatible operating room table
Leg spreader bars
C-arm fluoroscopy with monitor
Video tower set-up with light source, camera, and monitor
Standard surgical tray (with #11 scalpel blade and Kelly clamps)
Flexible cystoscope/nephroscope (16F standard)
Flexible ureteroscope (7.5F tip and shaft if using a 9.5/11F ureteral access sheath)
Rigid nephroscope (26F offset lens)
Lithotripsy equipment and supplies including grasping forceps, stone baskets, etc.
Pressurizable warming irrigation system
Disposable
0.035-inch 150-cm nitinol hydrophilic guidewire – straight tip and/or angled tip
0.035-inch 150-cm floppy-tip Bentson guidewire
0.035-inch 145-cm super-stiff guidewire
0.035-inch 260-cm floppy-tip Bentson exchange guidewire
5F open-ended ureteral catheter
8F/10F coaxial dilator-introducer set
Ureteral access sheath
18-G 15-cm conical tip, percutaneous renal trocar needle
5-mm fascial incising needle (Cook Urological, Spencer, IN, USA)
30F nephrostomy dilating balloon catheter with 30F renal access sheath
12F Foley catheter
10 mL Luer lock syringe
Optional
Sureseal II® Side arm self-sealing adapter (Applied Medical Corp., Rancho Santa Margarita, CA, USA)

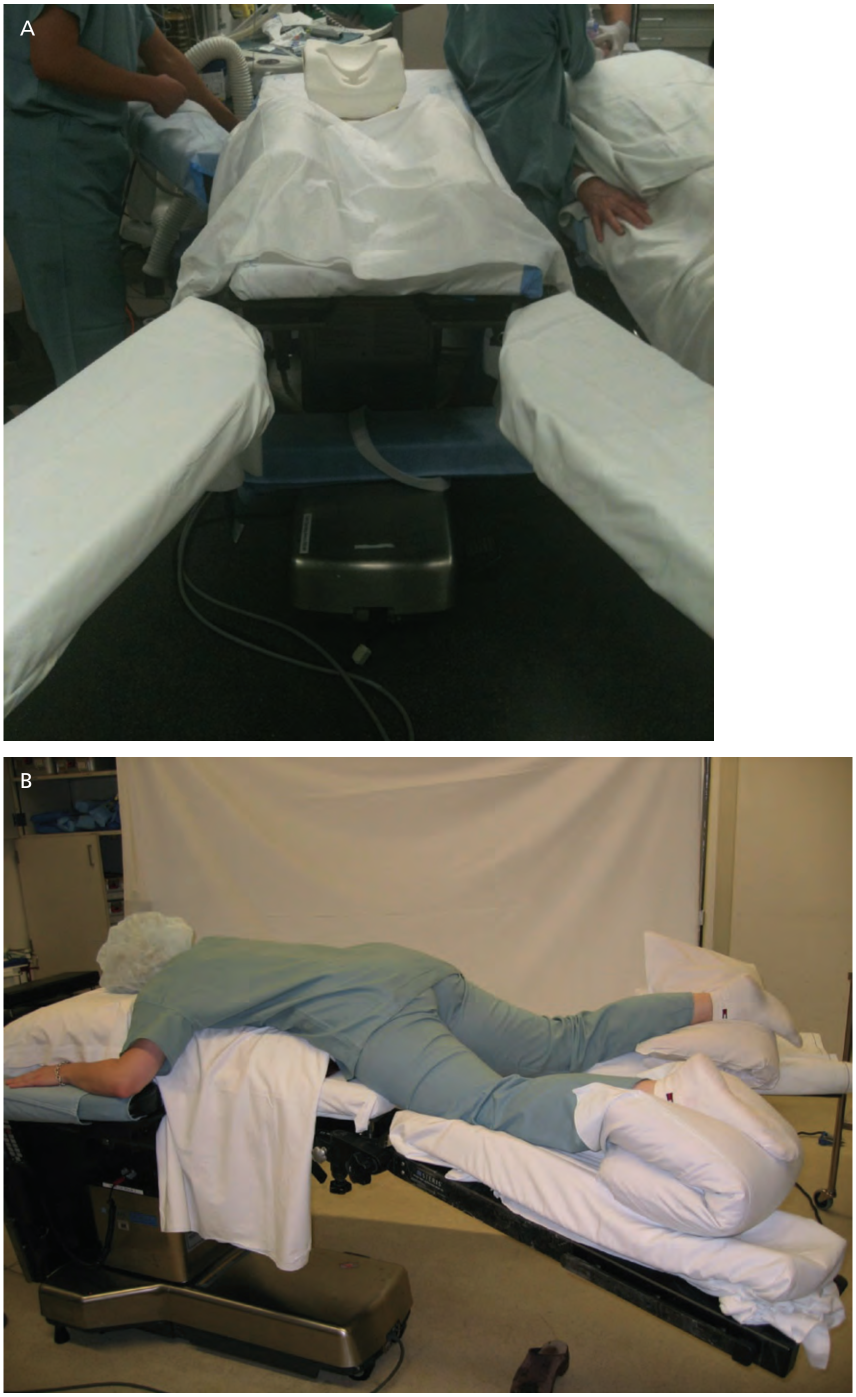

Figure 15.1 Patient positioning for endoscopic-guided percutaneous access: prone position with face and chest support, and legs on spreader bars. (A) Note the protective head support which rests on a mirror and allows the anesthesiologist access to the endotracheal tube and visualization of the patient's face during the procedure. (B) Pillows are placed under the patient's ankles to reduce strain on the peroneal nerve and the arms are in a neutral position in the "flying stance."

Percutaneous access

Once the ureteral access sheath is in position, the internal obturator of the sheath and the super-stiff wire are removed entirely. A flexible ureteroscope is advanced into the renal pelvis through the access sheath. Under fluoroscopic guidance, either air contrast or a double-contrast urogram via the ureteroscope (dilute contrast followed by 2–5 mL of air) is injected to map the calyceal system and identify the posterior calyx of choice, because the air will naturally move to the posterior calyces with the patient in the prone position. The desired calyx usually is the most superior posterior-facing calyx. This calyx is chosen for two reasons: it provides the most direct, straight-line access to the UPJ and it requires the least amount of angulation by the nephroscope to enter the middle and lower pole calyces. In patients with the infundibulum of the desired calyx obstructed by a large calculus or stone debris, ureteroscopic holmium laser lithotripsy is performed to allow the ureteroscope to be advanced into the desired calyx.

Using a hemostat or other clamp, the target calyx is "pointed" to with the tip of the clamp under fluoroscopic control with the C-arm fluoroscope in a 90° anteroposterior position. If a rib appears to be obstructing the intended calyx, then the fluoroscope may be obliqued 5–10° in a craniocaudal fashion to create an accessible angle without interposition of the rib. A transverse skin incision of about 5 mm is made to penetrate the dermis over the target calyx. An 18G percutaneous, conical-tip, trocar needle is advanced toward the tip of the ureteroscope residing in the desired calyx, which provides a definitive radio-opaque target. The advancement of the needle is monitored fluoroscopically to position the needle hub over the tip, over the target calyx, and endoscopically to monitor the entry of the tip of the needle into the calyx with the ureteroscope. The needle is initially advanced 4–6 cm into the flank to fix its trajectory. Next, the C-arm is rotated in an arc around the patient and away from the surgeon to a 25–30° position to monitor the advancement of the needle toward the calyx and ureteroscope. The insertion of the trocar needle into the collecting system is simultaneously monitored by both fluoroscopy and direct ureteroscopic visualization. The advancement of the needle as it punctures the calyx is monitored to ensure that the needle traverses the fornix of a posterior calyx and is not inadvertently advanced too deeply. The trocar needle obturator is then removed and a 0.035-inch nitinol guidewire is passed through the needle and is directed down the ureter alongside the access sheath, or within the access sheath if the sheath is larger and therefore can accommodate both the scope and the wire. Alternatively, the nitinol guidewire can be coiled in the renal pelvis. If the nitinol guidewire is passed down the ureteral access sheath, it can be delivered out through the urethral end of the access sheath. The nitinol wire can then be exchanged for a 260-cm Bentson exchange wire using a standard 5F open-ended ureteral catheter or a Kumpe catheter. The long exchange wire allows the maintenance of access along the entire access tract from the urethra to the percutaneous puncture, and can act as the safety wire for both the renal access and the retrograde access. If the long exchange wire is in place, the ureteral access sheath can be withdrawn and passed again over a super-stiff guidewire. If the nitinol wire is passed along the side of the ureteral access sheath, an attempt is made to pass it into the bladder. In this fashion, all subsequent coaxial maneuvers on the wire will be safely passed along the natural lumen of the urinary tract. Lastly, if the nitinol wire is curled in the renal pelvis, an attempt can be made to grasp it with a stone basket or grasper via the ureteroscope and bring it out through the urethral end of the access sheath [3]. The subsequent steps in the procedure are the same as if the wire were spontaneously passed into the sheath.

Once wire access has been attained, a #11 blade is used to enlarge the transverse flank incision to 30F or approximately 1 cm. The trocar needle is removed off the wire, and a 5-mm fascial incising needle is advanced over the exchange or super-stiff guidewire parallel to the ribs and only advanced to incise the lumbodorsal fascia. The fascial dilator should not be placed over a hydrophilic coated guidewire as this can shear off the outer coating of the guidewire, leaving foreign body debris within the tract. An 8/10F coaxial dilating sheath is then passed antegrade over the guidewire just into the collecting system to facilitate passage of a second or "working" guidewire (0.035-inch super-stiff wire); this is performed under ureteroscopic vision to confirm entry into the collecting system. The 8F obturator is removed, and a 0.035-inch super-stiff floppy-tip guidewire is passed into the renal pelvis, alongside the Bentson or exchange guidewire through the 10F catheter, and coiled or passed down the ureter. At this point, if an exchange wire has not been previously placed, the initial nitinol guidewire can be exchanged for a floppy-tip Bentson guidewire, if desired, or a mosquito clamp can be secured on both ends of the nitinol guidewire to ensure this does not slip out. The 10F sheath is removed, and if the nitinol or exchange wire has not been secured for through-and-through access, then the floppy-tip guidewire is sutured to the flank to serve as a safety guidewire. Tract dilation is performed under both endoscopic vision and fluoroscopic control. A 30F dilating balloon catheter is advanced over the working guidewire until the tip of the balloon is ureteroscopically seen to be just entering the target calyx. The nephrostomy tract is then dilated by inflating the balloon under direct ureteroscopic visualization and fluoroscopic control. Once the balloon of the dilating catheter has been inflated to the manufacturer's recommended pressure with the Leveen syringe, the 30F renal access sheath is advanced over the balloon until it visually reaches the tip of the balloon. The 30F sheath is then rotated under ureteroscopic guidance until all its edges are just visible within the collecting system. This ensures the entire beveled end of the access sheath is completely within the calyx. The balloon dilator is deflated and withdrawn. At this point, if a through-and-through guidewire has not been established, the ureteroscope can be directed into the percutaneous access sheath and an exchange wire passed through the ureteroscope and out of the percutaneous sheath. The ureteroscope can now be removed to allow maximum drainage of fragments and irrigation through the access sheath, the tip of which should be positioned at or slightly above the UPJ. The rigid or flexible nephroscope is introduced through the renal access tract and percutaneous nephrolithotripsy is performed.

Following the antegrade rigid and flexible nephrolithotripsy, and assumed removal of all the renal stone material, retrograde ureteroscopy is used to inspect the upper and middle pole calyces to ensure no stones were trapped behind the renal access sheath or positioned in an upper middle calyx not accessible by antegrade flexible nephroscopy. Any residual stone material can be managed easily in this manner with holmium laser lithotripsy and stone basketing in the standard fashion with fluoroscopic and contrast-enhanced guidance, to render the kidney stone free.

Results

Based on the initial trials of endoscopic-guided percutaneous renal access, all the urologists at our institution converted from fluoroscopic-only percutaneous access to endoscopic-assisted percutaneous access in May 2005 [4]. Sountoulides *et al*. recently reviewed our technique and results [5]. A retrospective analysis compared endoscopy-assisted percutaneous nephrolithotomy (PCNL) versus the standard, fluoroscopy-guided PCNL technique at the University of California, Irvine, CA, USA (Beck S. *et al*., unpublished data). Endoscopic-assisted PCNL (n = 51) was compared with a standard PCNL group (n = 70). All PCNLs were performed by two expert endourologists from 2002 to 2007 (n = 121). The cohorts were matched for age, body mass index, American Society of Anesthesiologists score, and stone parameters, with the average stone volume being 17 cm^3 in the endoscopic group and 16 cm^3 in the standard group. The endoscopic group was found to have less estimated blood loss (158 mL vs 211 mL, respectively, $P = .03$) and decreased postoperative transfusion rates (7.8% vs 21.4%, $P = .05$). Interestingly, the endoscopic cohort had fewer patients presenting with hydronephrosis compared to the standard group (12% vs 27%, $P = .04$). No difference was seen for intraoperative or perioperative complications, embolization rates, narcotic usage, or change in glomerular filtration rate. The endoscopic group had a slightly longer operative time compared to our standard group (227 min vs 208 min, $P = .1$). Finally, stone-free rates were similar between the endoscopic and standard groups (35% vs 46%; $P = .26$), as well as the number of patients with significant residual stone fragments (31% vs 26%, $P = .56$). "Stone free" was defined as no stone fragment on 2-mm slice CT scans of the abdomen and pelvis on postoperative day 1; significant stone fragments were considered to be 4 mm or larger.

One of the benefits to endoscopic-guided percutaneous renal access is the ease of obtaining a supracostal access tract. A recent review of the pulmonary complications from our institutional series (Khan F. *et al*., unpublished data) was compared with known complication rates in the literature. The endoscopic percutaneous access patients at our institution had significantly fewer pulmonary complications compared to those reported in the literature for fluoroscopic percutaneous access. In 111 consecutive patients who underwent endoscopic-guided percutaneous renal access at our institution, 84% required only a single puncture to obtain renal access, 93% underwent PCNL using an upper pole access, and 75% had a supracostal puncture. All patients had a postoperative chest radiograph (CXR). On CXR examination 11% had a pleural effusion, 3% a pneumothorax; and only two (1.8%) required a chest tube for clinically significant or symptomatic effusions and none for pneumothorax. In an outcomes meta-analysis for supracostal access by Lingeman *et al*., of 1580 patients underwent PCNL, 30% had supracostal access, and the overall incidence of pleural complications was 14.8% with 4.1% of these complications requiring intervention [6].

Conclusions

PCNL can be a safe and effective method for the removal of large kidney stones. Obtaining renal access from a superior renal calyx provides the most direct access to the renal pelvis, superior, middle, and lower calyces, and facilitates complete stone clearance using a single tract in most patients. Endoscopically-guided percutaneous renal access can provide single puncture, effective access to the desired calyx with minimal increase in operative time for patients undergoing PCNL for large volume upper tract renal stone disease. Our experience demonstrates the reduced pulmonary morbidity of this technique when utilized for a primarily upper pole calyx access.

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PART 4 Selection of Access and Dilation

CHAPTER 16

Upper Calyx Access for Percutaneous Nephrolithotomy

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Introduction

Stone-free clearance and improved patient outcomes during percutaneous nephrolithotomy (PCNL) are largely dependent on the appropriate selection of the access to the kidney. While standard PCNL is often performed through a subcostal lower calyceal approach, upper calyceal access through a supracostal approach can be ideal for many clinical situations. Traditionally, concerns for increased potential perioperative complications, particularly intrathoracic, have limited utilization of supracostal access [1]. However, with a good understanding of the anatomy surrounding the upper pole of the kidney and attention to a few technical considerations during the procedure, upper calyceal access through a supracostal approach can be performed safely and efficiently. In this chapter, we describe our surgical technique for upper calyceal access during PCNL and review the outcomes of this approach in the literature.

Indications and patient selection

During upper calyceal approaches, supracostal access is performed along the long axis of the kidney. This allows for direct entry to the upper calyx and optimal visualization of the renal pelvis, ureteropelvic junction (UPJ), and upper ureter [1]. The performance of rigid nephroscopy in the direction of the long axis of the kidney minimizes the torque requirement on the kidney and results in decreased bleeding and improved clearance rates [2]. In certain circumstances, a laterally situated intercostal tract can be placed between the tips of the 11th and 12th ribs, or an infracostal approach may be used to access the upper pole (Figure 16.1). While the risk of pleural injury may be less with these techniques as compared to the more superior supracostal puncture, the benefits in visualization outside the upper pole is limited with rigid instruments and may require increased reliance on flexible endoscopy [3].

Supracostal upper calyceal access can be advantageous in several clinical situations (Table 16.1). Upper pole access can be optimal for large upper pole stones (Figure 16.2) or for complete staghorn renal calculi (Figure 16.3). Direct access to the UPJ and proximal ureter may be beneficial for treatment of large or impacted proximal ureteral calculi, particularly with concomitant renal pelvic stones, or need for antegrade endopyelotomy during UPJ obstruction management. Similarly, stones in more complicated renal systems, such as an upper pole calyceal diverticulum, or complex lower pole configurations may be more amenable to an upper calyx approach. In situations with superior kidneys located above the ribs, middle or even lower calyceal access may require a supracostal approach. Conversely, in a few patients, upper calyx puncture may be possible via a subcostal route, depending on the renal anatomy. For example, due to its incomplete ascent, horseshoe kidneys are best accessed in the upper pole [3]. However, this can usually be performed from a subcostal approach.

Anatomic considerations

A general knowledge of the anatomy of the upper pole of the kidney in relation to the surrounding structures is necessary to minimize complications during supra-

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Image not available in the electronic edition

Figure 16.1 Upper pole access can be obtained through a supracostal, intercostals, or infracostal approach. Reproduced with permission from Sharon Teal, Office of Visual Media, Indianapolis, ID. Figure © Sharon Teal (medical illustrator).

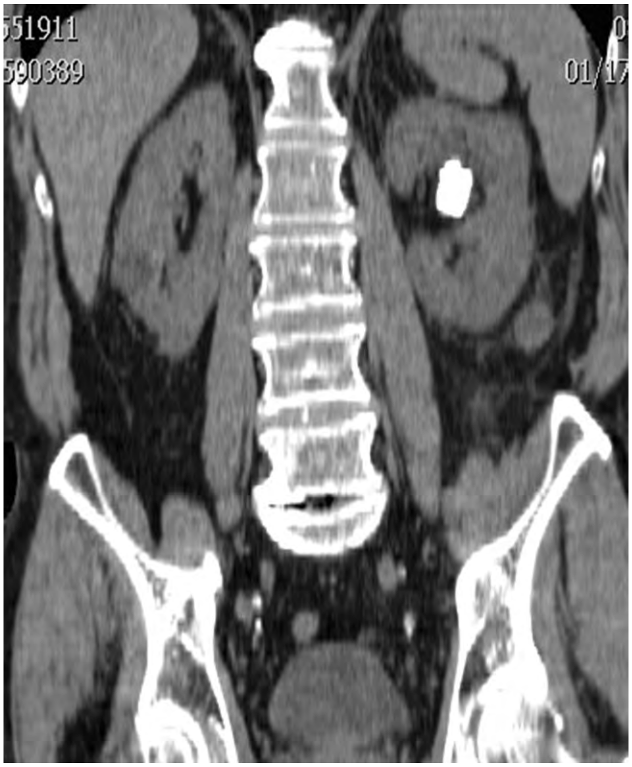

Figure 16.2 Coronal CT imaging shows a large upper calyceal stone.

Table 16.1 Indications for upper pole/supracostal access.

Large stone burden
Staghorn calculi
Large upper pole stones

Need for direct access to uteropelvic junction (UPJ)
Large/impacted proximal ureteral stones
UPJ obstruction requiring anterograde endopyelotomy

Complex anatomy
Upper pole calyceal diverticulum
Complex lower pole calculi
Horseshoe kidney
Superiorly located kidneys

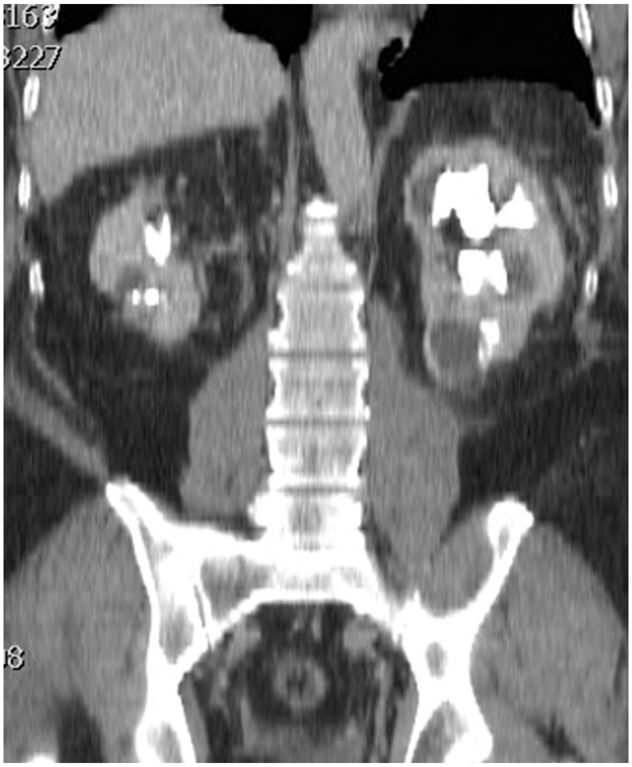

Figure 16.3 Coronal CT imaging shows a complete staghorn renal calculus.

costal access to the upper calyx. The intercostal nerve and vessels are located along the inferior portion of each respective rib. Puncture sites are directed to the middle portion of the intercostal space to avoid injury to the intercostal artery and development of a hemothorax. In most situations, lateral posterior renal calyces are targeted during percutaneous access to avoid the major branches of the renal artery. Posterior calyces generally transverse Brodel's bloodless line, the avascular renal plane between the anterior and posterior divisions of the renal artery. Additionally, posterior calyces offer the shortest access path to the collecting system [3]. Needle punctures should be directed along the axis of the renal calyx through the center of the renal papilla to avoid infundibular or renal pelvic puncture. Injury to interlobar arteries has been noted in up to 67.6% of kidneys following upper pole infundibular puncture and to retropelvic vessels in 33% following direct renal pelvic puncture [4].

The concern for intrathoracic injury following upper calyceal access is secondary to the close relationship of the upper kidney to the lungs and pleura. The upper portions of both kidneys are located anterior to the posterior portion of the 11th and 12th ribs. A review of 90 normal supine intravenous urograms during full expiration noted that 85% of upper renal calyces are located above the 12th rib [5]. In the prone position, further cephalad movement of the kidney occurs in 80% of patients [6]. Despite controlled maximal expiration, this cephalad movement results in an estimated likelihood of lung injury following supracostal access of 29% on the right side and 14% on the left [7]. The posterior diaphragm arises from the distal ends of the 11th and 12th ribs, the tip of the L1 transverse process, and the anterior aspect of the upper lumbar vertebral body [8]. During full inspiration, the posteroinferior margin of the lung expands to fill the posterior costophrenic recess. During expiration, the lung retracts and the pleura ascends cranially and laterally on the ribs [9]. The lower limit of the posterior parietal pleura crosses the 12th rib obliquely near the lateral border of the erector spinae muscles. In the midscapular line, the visceral pleura has a similar relationship at the 10th rib [10]. The initial needle puncture for a supra-12th rib access is advocated at maximal expiration and lateral to the erector spinae muscles in the 11th and 12th interspace to avoid lung and pleural injury. Supra-11th rib access can be performed in a similar fashion between the 10th and 11th rib interspace [11].

Surgical technique

Our percutaneous approach for upper calyceal access is similar to that used for the lower pole. At the onset of the procedure, the patient is placed in the dorsal lithotomy position. Using rigid cystoscopy, we place a 5F open-ended ureteral catheter to allow opacification of the renal collecting system. After subsequent placement of a Foley catheter, the patient is placed in the prone swimmer's position. A chest roll is placed horizontally to facilitate ventilation, with the neck maintained in a neutral position. An additional roll is used to slightly elevate the side of interest in order to align the posterior calyces in a more vertical position. The ipsilateral upper extremity is placed at 90° flexion, while the contralateral arm is positioned parallel to the patient. Particular attention is given to properly pad all pressure points and secure the patient to the table. Using biplanar fluoroscopy, we perform either the "bullseye" or "triangulation" technique for percutaneous access. The bullseye technique is described in Chapter 13 and here we will detail our supracostal approach using the triangulation technique.

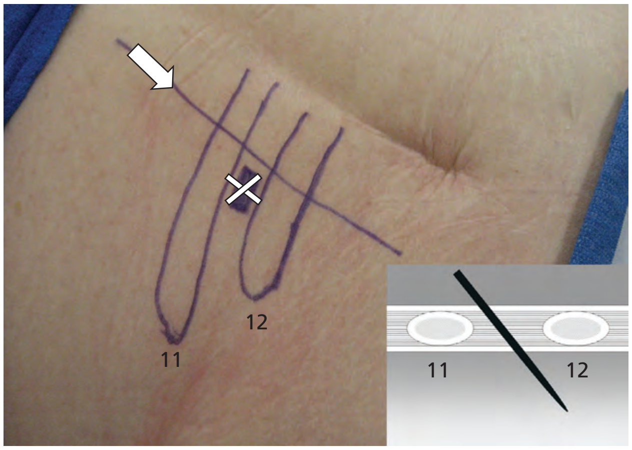

Figure 16.4 Initial puncture for a supra-12th rib approach is lateral to the erector spinae muscles (arrow) at the inferior border of the 11th rib angled towards the middle of the intercostal space (X).

Triangulation technique

For upper calyceal access, we generally prefer a puncture site within the 11th and 12th intercostal space, just lateral to the erector spinae muscles. A supra-11th rib puncture is avoided when possible. Following identification of the targeted upper pole calyx under fluoroscopy, the triangulation technique is started with an 18G diamond-tipped access needle puncture in the inferior border of the 11th rib at the skin (Figure 16.4). The needle is angled acutely so that it enters at the center of the intercostal space, thus avoiding the intercostal nerve and vessels of the 11th rib. Biplanar fluoroscopy is performed using the C-arm in two positions, anteroposterior and oblique. The anteroposterior view is along the plane parallel to the line of puncture. When the C-arm is in the anteroposterior position, adjustments to the needle position are made in the mediolateral (left–right) direction (Figure 16.5). The oblique view is obtained by rotating the C-arm through 30°. When the C-arm is positioned obliquely, adjustments to the needle position are made in the cranial–caudal (up–down) orientation with care not to drift into the mediolateral position (Figure 16.6). Ventilation is suspended in full expiration as the access needle is advanced towards the desired calyx. The C-arm is maintained in the oblique position in order to gauge the depth of puncture. After initial advancement, the C-arm is rotated back to the AP view to

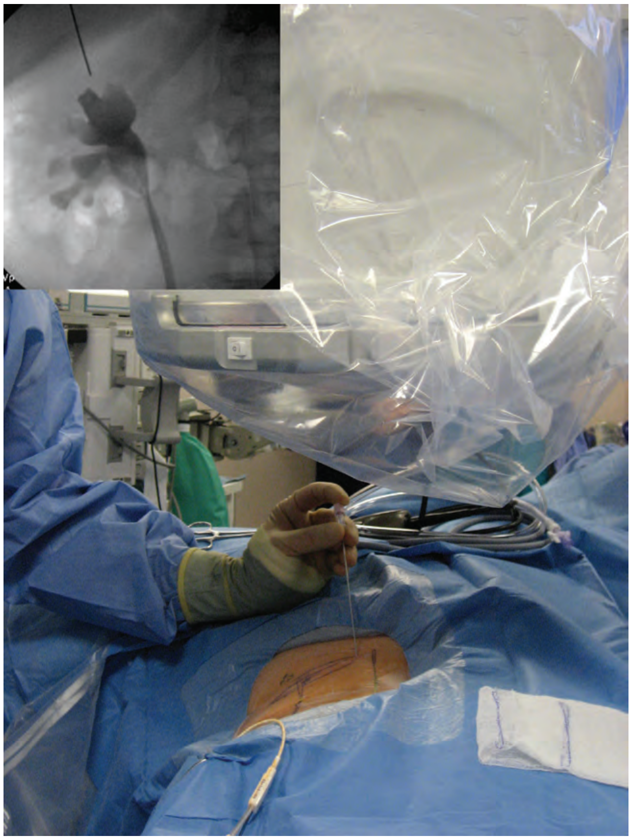

Figure 16.5 Using the triangulation technique for supracostal percutaneous renal access, adjustments to the needle position are made in the mediolateral (left–right) direction when the C-arm is in the anteroposterior position (along the plane parallel to the line of puncture).

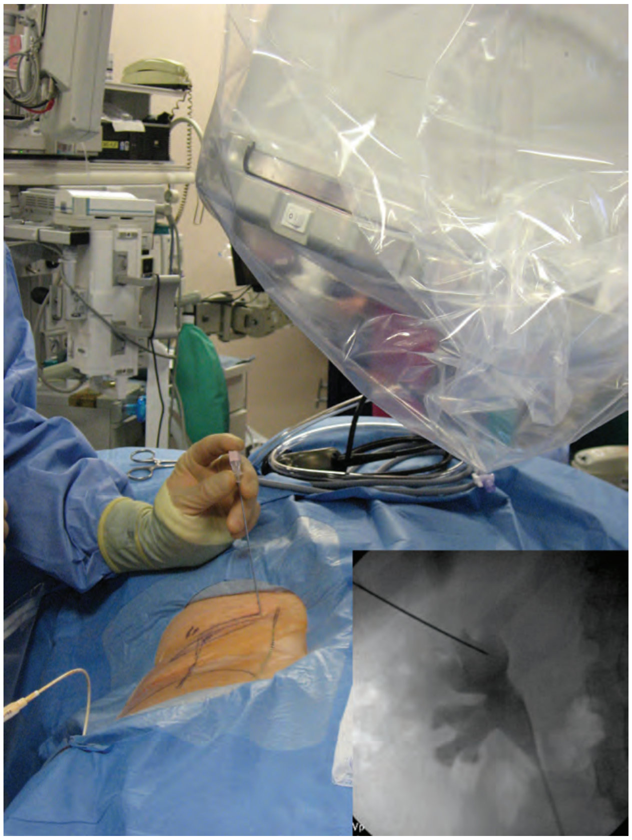

Figure 16.6 Using the triangulation technique for percutaneous renal access, adjustments to the needle position are made in the cranial–caudal (up–down) direction when the C-arm is in the oblique position (rotating the C-arm 30º).

confirm the mediolateral orientation before continuing needle movement in the oblique view. Simultaneous retrograde instillation of contrast via the open-ended catheter allows for collecting system opacification and identification.

After entry into the renal calyx, aspiration of fluid is performed to confirm the needle position in the collecting system. A 0.038-inch hydrophilic nitinol core glidewire is advanced through the access needle and manipulated down the ureter if possible. If entry to the ureter is prohibited, the wire is coiled in the renal pelvis or in the calyx that is accessible and furthest away from the calyx of puncture. An 8F fascial dilator and subsequently a 5F Cobra-tipped angiographic catheter are sequentially passed over the glidewire in order to facilitate wire positioning in the ureter. The glidewire is next exchanged for an Amplatz super-stiff wire. A second standard guidewire is placed as a safety wire into the ureter and secured to the drape following placement of an 8/10F coaxial dilator over the super-stiff wire. A NephroMax balloon is advanced over the super-stiff wire until the radio-opaque marker is noted just inside the collecting system. Following balloon inflation to 14–20 atm, the 30F Amplatz sheath is advanced over the balloon into the collecting system and standard stone treatment is performed.

Some patients, such as those with complete staghorn calculi, may require additional access into a different calyx following initial percutaneous tract placement in the upper calyx. In this situation, the Amplatz sheath is left in the upper pole while working through the second access tract in order to prevent excessive extravasation from the upper pole calyx into the pleural cavity.

At the conclusion of the procedure, fluoroscopy is performed over the ipsilateral chest and lung fields to exclude the presence of hydrothorax. In the operating room, a pigtail catheter is inserted into the chest under fluoroscopic guidance in patients noted to have significant hydrothorax or pleural effusion. Patients who are symptomatic or for whom there is concern for a hydrothorax in the postoperative period are followed with an upright chest X-ray in the recovery room and monitoring of clinical respiratory vital signs. In the postoperative period, patients with symptomatic fluid collections

Table 16.2 Operative parameters following supracostal renal access/percutaneous nephrolithotomy (PCNL).

Study	No	Additional access (%)	Overall stone-free rate (%)	Ancillary procedures*
Golijanin *et al*. 1998 [16]	115	23 (20)	78 (67.8)	53 (46)
Kekre *et al*. 2001 [17]	102	Not specified	81 (79.5)	Not specified
Gupta *et al*. 2002 [18]	63	15 (23.8)	57 (90)	13 (20.6)
Lojanapiwat and Prasopsuk 2006 [19]	170	0 (0)	140 (82.4)	6 (3.5)
Shah *et al*. 2006 [20]	144	22 (15.3)	127 (88.2)	5 (3.5)
Sukumar *et al*. 2008 [21]	110	9 (8.2)	95 (86.4)	15 (13.6)
Shaban *et al*. 2008 [22]	30	11 (36.7)	24 (88.9)	3 (11.1)
Lang *et al*. 2009 [23]	103	Not specified	91 (88)	Not specified

*Includes shock-wave lithotripsy, second-look PCNL, ureteroscopy.

are managed by tube thoracostomy. On the first postoperative day, a stone-protocol CT scan, which includes the lung bases, is performed in all patients to evaluate for residual stones.

Alternative technique

To avoid supracostal puncture, some authors have advocated a renal displacement technique. The initial placement of a sheath or dilator is performed via an interpolar renal access in order to allow for torque of the kidney downward. This can be held by an assistant while upper calyx puncture is performed via a subcostal route [12, 13]. Additionally, simultaneous fluoroscopy with retrograde flexible ureteroscopy via a ureteral access sheath has been described for endoscopically-guided percutaneous access [14]. This modification may aid in rapid and precise percutaneous puncture into the desired upper pole calyx [15].

Outcomes

Reported stone-free rates following supracostal access PCNL are comparable to infracostal approaches and range between 68% and 90% [16–23] (Table 16.2).The lack of strict criteria defining stone-free status with utilization of multiple imaging modalities may account for some of the variation in reported outcomes. Additional percutaneous access was required up to one-third of the time; this is not surprising given that complete staghorn calculi are one indication for upper pole access. Similarly, ancillary procedures, including second-look PCNL, ureteroscopy, and shock-wave lithotripsy, were performed in 3–46% of cases.

Operative complications (see also Chapters 30–32)

Overall complication rates following supracostal access during PCNL range from 10% to 26% (Table 16.3) [2, 9, 16–23]. Significant hemorrhage requiring blood transfusion or bacteremia and sepsis can occur following any PCNL procedure. Specific complications in relation to supracostal approaches are described in more detail below.

Pulmonary complications

Intrathoracic complications have been reported in approximately 1–15.3% of cases [2, 9, 16–23]. Supra-11th access, in particular, is associated with increased occurrence of pulmonary injuries. In one series, six of 26 (23.1%) supra-11th PCNLs resulted in intrathoracic complications as compared to one of 72 (1.4%) supra-12th rib accesses [2]. Hydrothorax is the most common pleural injury noted secondary to collection of irrigation fluid in the pleural space. The occurrence can be minimized with the judicious use and positioning of the Amplatz sheath to avoid leakage into the pleural space and maintenance of a low-pressure system as well as adequate renal drainage postoperatively [18]. A delayed hydrothorax may occur secondary to urine leakage through the PCNL tract to the pleura, often secondary to the formation of a renopleural fistula. Prolonged fluid accumulation in the setting of a urinary tract infection can manifest as an empyema. A hemothorax may occur following injury to the intercostal vessels during initial needle puncture. The occurrence of an isolated pneumothorax, however, is uncommon [24].

The diagnosis of pulmonary injuries can be made intraoperatively and/or postoperatively. At the conclusion of the PCNL, prone fluoroscopy of the ipsilateral lung fields should be performed in all cases involving supracostal access. A distinct fluid demarcation laterally along the chest wall from the lung or an obscured costophrenic angle warrants further evaluation or intervention if ventilation is difficult. An upright chest X-ray or computed tomography (CT) scan can be used to confirm the fluid density at the lung base in less defined cases

Table 16.3 Supracostal complications associated with renal access/percutaneous nephrolithotomy (PCNL).

Study	No	Supra-12th (%) Supra-11th (%)	Overall number of complications (%)	Sepsis/ bacteremia (%)	Thoracic (%) Pneumothorax Hemo/hydrothorax Renopleural fistula Needed treatment	Other organ injury (%)	Significant blood loss/ required blood transfusion (%)
Golijanin *et al.* 1998 [16]	115	115 (100)	30 (26.1)	0 (0)	4 (3.8) 0 (0) 4 (3.5) 0 (0) 4 (3.5)	0 (0)	20 (19.2)
Munver *et al.* 2001 [2]	98	72 (73.5) 26 (26.5)	16 (16.3)	1 (1)	7 (7.1) 1 (1) 4 (4.1) 2 (2) 6 (6.1)	0 (0)	4 (4.1)
Kekre *et al.* 2001 [17]	102	102 (100)	10 (9.8)	0 (0)	10 (9.8) 1 (1) 9 (8.8) 0 (0) 9 (8.8)	0 (0)	0 (0)
Gupta *et al.* 2002 [18]	62	62 (98.4) 1 (1.6)	14 (22.2)	7 (11)	7 (11) 0 (0) 7 (11) 0 (0) 4 (6.3)	0 (0)	6 (9.5)
Yadav *et al.* 2006 [9]	332	328 (98.8) 4 (1.2)	74 (22.2)	53 (16)	11 (3.3) 0 (0) 11 (3.3) 0 (0) 7 (2.1)	0 (0)	6 (1.8)
Lojanapiwat and Prasopsuk 2006 [19]	170	170 (100)	31 (18.2)	1 (0.6)	26 (15.3) 0 (0) 26 (15.3) 0 (0) 9 (5)	0 (0)	4 (2.4)
Shah *et al.* 2006 [20]	144	110 (76) 35 (24)	19 (13.2)	6 (4.1)	5 (3.5) 0 (0) 5 (3.5) 0 (0) 1 (0.7)	0 (0)	7 (4.9)
Sukumar *et al.* 2008 [21]	110	110 (100)	13 (11.8)	2 (1.8)	10 (9.1) 0 (0) 10 (9.1) 0 (0) 10 (9.1)	0 (0)	2 (1.8)
Shaban *et al.* 2008 [22]	30	24 (80) 6 (20)	4 (13.3)	1 (3.3)	2 (6.6) 0 (0) 1 (3.3) 1 (3.3) 2 (6.6)	0 (0)	1 (3.3)
Lang *et al.* 2009 [23]	103	Not specified	11 (10.7)	0 (0)	1 (1.0) 0 (0) 1 (1) 0 (0) Not specified	0 (0)	7 (6.8)

with high suspicion during the postoperative setting. While under anesthesia, concerning fluid collections may be aspirated during hyperventilation or treated with tube thoracostomy [25]. In the postoperative setting, a period of observation may be warranted with small fluid collections, but aspiration or tube thoracostomy connected to underwater drainage should be utilized in symptomatic patients. An evaluation by a thoracic surgeon for potential thoracotomy or video-assisted thoracoscopic surgery (VATS) may be required for nonimproving or infected pulmonary complications. In patients with ureteral stents that show delayed presentation, the effusion may be secondary to stent-related reflux and additionally treated with anticholinergics and maximal bladder decompression. Patients without ureteral stents may have delayed effusions secondary to transient obstruction from small calculi or blood clots, and require ureteral stent and Foley catheter placement [24].

Other organ injury

Though less common than pulmonary complications, injuries to adjacent organs, including the liver, spleen, and intestines, can rarely occur during upper calyceal access. A retrorenal left colon, occurring in 10% of patients in the prone position, may prohibit access to the 10th or 11th intercostal space with increased risk associated with medial punctures [26]. Additionally, a supra-11th access could puncture the liver in 14% and spleen in 33% of patients, particularly during inspiration [7]. In hemodynamically stable patients, liver injuries can often be managed conservatively with tube drainage and serial monitoring [27]. Moreover, transhepatic PCNL has been reported to be safe if necessary [28]. Splenic injuries, however, are associated with increased bleeding and may require immediate exploration and splenectomy [29]. This underscores the importance of preoperative CT imaging to determine the relationship of adjacent structures, as well as evaluation under fluoroscopy in multiple planes intraoperatively prior to needle placement in order to minimize injury to other organs [30].

Postoperative pain

While not typically quantified in most studies, supracostal access during PCNL results in increased discomfort as compared to subcostal approaches secondary to traversing of the diaphragm [20]. During needle placement, medial puncture through the paraspinal muscles is associated with increased pain and should be avoided if possible [3]. Several recommendations have been made to decrease pain following upper pole access. Intercostal nerve block has been advocated as a method to minimize supracostal tube discomfort [31]. Instead of placing a supracostal tube, a lower pole nephrostomy tube may be placed at the conclusion of the procedure via a second nondilated subcostal puncture and allowing the supracostal puncture site to close [32]. Additionally, downsizing to a small-bore percutaneous catheter at the conclusion of the procedure is associated with reduced postoperative symptoms as compared to large percutaneous catheters [33]. Tubeless supracostal PCNL has been reported with decreased need for postoperative analgesia [18, 34, 35]. Tubeless PCNL should be performed only in cases in which complete stone extraction is a near certainty. Candidates for tubeless approaches should meet strict criteria, including no collecting system perforation or significant bleeding [35]. Tubeless procedures should also be avoided in patients with concerns for magnesium ammonium phosphate stones to minimize any potential spread of infection to the chest.

Conclusions

Supracostal percutaneous access to the upper pole of the kidney during PCNL is a useful technique when optimal visualization is required for the upper calyx, UPJ, and proximal ureter. Supra-12th rib puncture should be approached lateral to the erector spinae muscles towards the superior portion of the rib during maximal expiration. Supracostal access above the 11th rib should be avoided when possible. Intraoperative fluoroscopy of the lung fields should be performed at the conclusion of the procedure, and a strong suspicion for pulmonary injuries should be maintained in the postoperative period. Patients should be counseled appropriately regarding the potential risks and complications when upper calyceal access is anticipated, particularly with regards to intrathoracic complications. However, with attention given to anatomic considerations, supracostal access to the upper pole can be obtained safely and efficiently to contribute to successful percutaneous renal surgery.

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CHAPTER 17

Percutaneous Renal Access without Image Guidance

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Introduction

In 1955, Goodwin described the percutaneous placement of a needle nephrostomy for hydronephrosis, opening the door to percutaneous renal access [1]. The rapid dissemination of image-guided techniques in urology and interventional radiology has contributed to the innovation of percutaneous renal procedures. Simple drainage has evolved into percutaneous treatments for stone disease, upper tract and renal cancers, and urinary diversion/drainage, amongst others. The advancement of endourologic techniques has led urology into the minimally invasive era. This rapid innovation has forced urologists to become proficient in percutaneous renal procedures, offering optimal treatment for the expanding number of pathologies amenable to percutaneous treatment.

Indications

Percutaneous access has been described using various imaging modalities, including ultrasound and fluoroscopy [2–6]. Fortunately, there are few instances in which access must be achieved blindly. Urologists have largely been dependent upon interventional radiology colleagues for percutaneous drainage, but it is becoming an essential skill as it is the procedure of choice for renal access in the acute setting. The inability to obtain retrograde access or opacify the collecting system in a retrograde fashion may be due to previous cystectomy and urinary diversion, locally invasive prostate cancer, benign prostatic hyperplasia, urinary tract fistulas, alternate primary cancers obstructing the ureters, pelvic lipomatosis, and retroperitoneal fibrosis [7]. Renal insufficiency may preclude the use of intravenous pyelography. On rare occasions, access to various imaging modalities may be unavailable, or proficiency with image-guided percutaneous nephrostomy placement may be lacking.

Anatomy (see also Chapter 6)

The retroperitoneal location of the kidney allows for relatively safe percutaneous access via a posterior approach. Nephrostomy placement without image guidance is completed utilizing anatomic landmarks, assuming normal renal anatomy. A thorough understanding of renal anatomy and relations is essential to avoid complications and gain access to the collecting system [8].

The kidney is a mobile organ and its position can vary depending on patient position and phase of respiration. With respiratory excursion, the kidneys descend on average 4–5 cm, reaching as far as the iliac crest. Generally, the right kidney lies 1–2 cm lower than the left due to its position below the liver. The pleural reflection is posterior to the upper third of both kidneys and needle placement above the 12th rib places patients at additional risk for pneumothorax. The renal hila are directed ventromedially and are approximately 5 cm lateral from the margin for the spinous process of the L1 vertebra. The right kidney is intimately associated with the liver anteriorly and laterally, the colon anteriorly, and the duodenum and vena cava anteriorly and medially. The left kidney is intimately associated with

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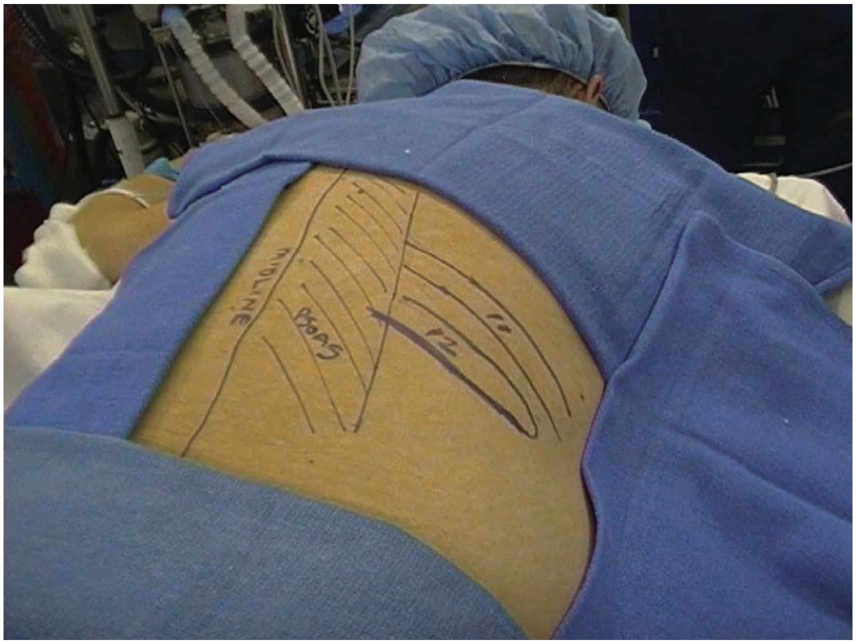

Figure 17.1 Muscular and bony relations relevant to percutaneous renal access.

the spleen laterally, colon anteriorly, and tail of the pancreas and aorta anteriorly and medially. Careful needle placement is crucial for safe nephrostomy placement and to avoid visceral organ injury.

Bony and muscular relations

The average size of each kidney is approximately 11 cm in length, 6 cm in width, and 3 cm in thickness. They lie between the 12th thoracic (T12) and 3rd lumbar (L3) vertebrae. The 11th and 12th ribs are superficial to the upper pole of the kidneys. The intercostal neurovascular bundle courses inferiorly to the corresponding rib, and should be avoided if possible (Figure 17.1).

The kidneys lie in an oblique plane abutting the psoas which directs its longitudinal axis 30° from the midline, and renders the lower poles more anterior (further from the skin surface) in the prone position. The lumbar notch has been described as a depression that can be palpated, allowing for safe placement of needle puncture [9]. The superior margin consists of the latissimus dorsi and 12th rib, is medially bounded by the sacrospinalis and quadratus lumborum muscles, and laterally by the transversus abdominus and external oblique muscles (Figure 17.2).

Vascular considerations

The renal artery arises from the aorta at the L1 level, dividing into anterior and posterior branches. The anterior branch divides into three to four segmental arterial branches which supply the anterior and polar regions. The posterior branch gives rise to one posterior segmental renal branch that supplies the posterior surface of the kidney, excluding the polar regions. The segmental arteries give rise to a variable number of interlobar arteries that divide and become the arcuate branches, which subsequently become the interlobular arteries. The interlobular arteries course peripherally in the cortex to supply the afferent arterioles of the glomeruli. Broedel's line represents a watershed zone between the distribution of the anterior and posterior divisions of the renal artery [10]. It allows for percutaneous access through a relatively avascular plane that avoids major arterial branches, potentially avoiding excessive bleeding, pseudoaneurysm formation, and development of arteriovenous malformation (Figure 17.3).

Calyceal anatomy

Calyceal architecture exhibits a considerable degree of variability. Calyces can be divided into superior, midzone (anterior and posterior), and inferior. Two types of calyceal configurations have been reported, the Broedel and Hodson types [10, 11]. The Broedel configuration describes anterior calyces as being angled medially and posterior calyces more peripherally. The Hodson configuration is in direct opposition with the anterior calyces angled laterally, and the posterior calyces more medially. Kaye and Reinke studied calyceal distribution on computed tomography (CT) imaging and determined that the Broedel type is more

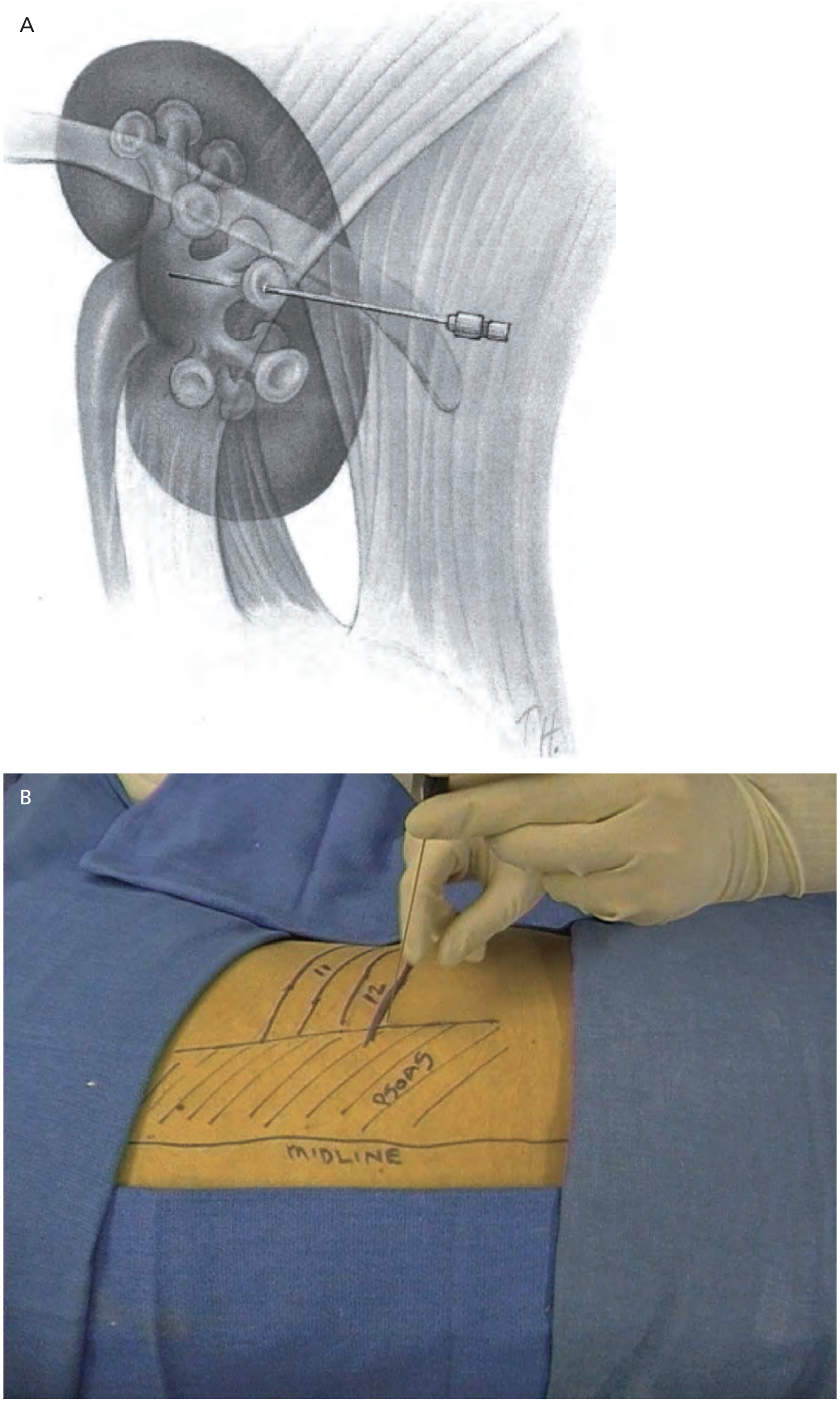

Figure 17.2 (A) Lumbar notch. The superior margin consists of the latissimus dorsi and 12th rib, is medially bounded by the sacrospinalis and quadratus lumborum muscles, and laterally by the transversus abdominus and external oblique muscles. (B) Needle puncture through lumbar notch in anatomic model.

commonly seen on the right, and the Hodson type on the left [12].

In clinical practice, emergent nephrostomy decompression without image guidance can most easily be done using a posterolateral approach to access a posterior or lower pole calyx.

Technique

Prior to proceeding, the patient should be educated on the inherent risks of percutaneous nephrostomy. The lack of image guidance places the patient at slightly greater probability of experiencing an adverse event, as

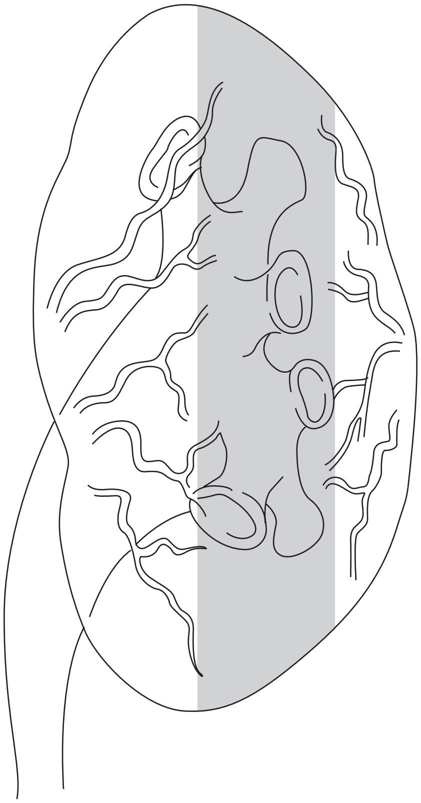

Figure 17.3 Broedel's avascular zone (shaded).

multiple passes may be required to obtain initial access. Preprocedural laboratory values are reviewed, including a coagulation profile, platelet count, and urinalysis. Preoperative broad-spectrum antibiotics are given, and narrowed according to sensitivity profiles when clinically appropriate. General anesthesia is not required in most cases, as use of a local anesthetic and sedation is usually sufficient. The patient is positioned prone with all pressure points padded. The ipsilateral flank is prepped widely, and draped with adequate exposure to facilitate choosing the site of skin puncture.

Initial skin puncture is guided by anatomic landmarks, as discussed previously. The lumbar notch can be palpated, and is an anatomic window that provides the path of least resistance when determining the ideal tract for collecting system access. The 12th rib is identified, and needle entry should be below this point to minimize the risk of pneumothorax and intercostal nerve irritation. After selection of the puncture site, the skin and subcutaneous tissues are infiltrated with local anesthetic.

An 18G sheathed access needle provides stability, can be torqued easily, and does not require exchange to place a suitable working wire. An obstructed, dilated system provides a larger target area to obtain access and can be achieved safely with the convenience of a larger needle. Alternatively, a 22G spinal needle may be used with a 0.018-inch wire for initial entry. A smaller gauge needle can diminish the risk of clinically significant hemorrhage associated with renal puncture, as well the risk of visceral organ injury [13]. The needle is positioned at the lumbar notch, oriented slightly cephalad, and angled approximately 30° in relation to the vertical axis. The needle is advanced to a depth of 4–5 cm and aspiration can confirm entrance to the collecting system. If initially unsuccessful, negative pressure is applied to the needle while being withdrawn as it may then be slowly pulled back into the collecting system. The needle can be repositioned at the same puncture site and slight modification of angle and depth will allow access to the pelvicalyceal system. Once access is confirmed with aspiration of urine, a hydrophilic atraumatic tipped guidewire is passed gently into the system, to ensure no resistance is encountered. If the initial indication for blind nephrostomy was the inability to opacify the collecting system, an antegrade pyelogram can be performed to retarget an alternate calyx if deemed necessary. In the case of obstruction causing infection, the primary goal is drainage, and which calyx is accessed becomes less relevant. The remaining steps mirror those of the standard percutaneous access. A skin incision is made, and tract dilation is performed 2–4F greater than the size of the desired nephrostomy tube. The nephrostomy tube is passed over the guidewire and deployed along the percutaneous tract in the collecting system.

Results

The blind percutaneous technique should be reserved for emergent cases in which retrograde access cannot be obtained, opacification of the collecting system is not feasible, or imaging is unavailable. Chien *et al*. reported a 98% success rate in a retrospective review of 40 blind percutaneous renal access procedures, equivalent to that of image-guided access [7]. A single procedure required ultrasound guidance to obtain successful access. No adverse events or complications were reported in their series. The majority (75%) of initial collecting system entries were at the renal pelvis with 17.5% being achieved within the kidney itself, and the remaining being obtained in the upper/lower pole. A comparison of retrograde stent placement versus nephrostomy tube insertion for obstructing calculi with evidence of clinical infection revealed no significant differences in time to clinical improvement or length of stay, although those undergoing percutaneous nephrostomy had increased perceived back pain [14].

Complications

Percutaneous renal access without image guidance theoretically places patients at increased risk of morbidity.

Bleeding complications arise when segmental or interlobar branches are injured and the incidence of severe bleeding ranges from 0% to 2.6% in published series [15]. These can be reduced by ensuring that preoperative coagulation abnormalities are addressed, 22G spinal needle placement towards Broedel's avascular plane when possible, and minimizing the number of punctures [16]. Emergent decompression is largely completed for an obstructed, potentially infected urinary tract. The incidence of septic complications ranges from 1% to 21%, and decreasing manipulation and broad-spectrum antibiotics preoperatively can reduce these events [17, 18]. The risk of pleural transgression increases with intercostal punctures, the rate of pneumothorax and effusion reaching up to 4% and 8%, respectively [19–21]. If intercostal puncture is absolutely necessary, a postoperative chest radiograph should be completed, especially when access is obtained blindly. Bowel perforation is fortunately a rare complication, reported in less than 1% of cases, and can be treated conservatively in the majority of cases [22–24]. Visceral organ injury is also rare, yet patients must be informed of this potential complication [25].

Conclusions

Blind percutaneous renal access can be performed safely, with minimal morbidity when all preoperative factors are addressed. In the appropriate setting, knowledge of this technique can provide urologists with an essential skill set to expedite management and improve patient care.

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CHAPTER 18

Retrograde Access for Percutaneous Renal Surgery

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Introduction

As percutaneous surgery has usurped the role of gold standard treatment for complex stone disease, refinement in access techniques continues to be an active area of development. Certainly access to the renal collecting system is one of the more difficult steps and comfort with access techniques provides the surgeon with the capability to address almost any challenging situation. Nevertheless, occasions do arise when anatomic considerations make access difficult or stone burden is so severe that ancillary measures may be welcome or even required.

At the time of writing of this book, flexible ureteroscopy (URS) has become a standard element in the endourologist's armamentarium in the USA and much of Europe. A large majority of studies have focused on the distinct roles for URS and percutaneous nephrolithotomy (PCNL) and have set out to define which technique is best suited for specific clinical situations. Several articles have addressed the capabilities of URS in the setting of large stone burdens [1, 2]. A large prospective randomized trial has documented a relatively low stone-free rate with URS for lower pole stones of greater than 1 cm with rigorous follow-up [3].

Instead of considering PCNL and URS independently, use of both approaches concurrently may provide a means to perform lithotripsy in complex situations. Furthermore, several groups have described routine use of this technique in order to optimize results and improve efficiency in all cases of percutaneous surgery [4–6]. In this chapter we describe perioperative considerations, surgical technique, and clinical outcomes of retrograde access for percutaneous surgery.

Development of the retrograde access technique

In 1983, two groups independently described techniques for retrograde creation of a nephrostomy tract [7, 8]. Hunter *et al*. used a 9F. outer retrograde catheter passed transurethrally to direct a catheter/needle assembly towards a desired calyx [7]. Under fluoroscopic guidance, the needle was then advanced through the calyx, renal capsule, perirenal soft tissues, and ultimately skin to establish a percutaneous tract. After dilation of the tract, the stone could be treated using a standard PCNL technique. The authors performed access successfully in 15 of 20 canine kidneys and then performed one staged clinical case under sedation. Advantages of the technique mentioned by the authors included familiarity of the anatomy for urologists, directed puncture of the desired calyx, easier access in complex cases, including obese patients and those with nondilated systems, potentially less blood loss due to puncture direction away from hilar vessels, and greater distance of the operator from the fluoroscope.

The technique of Lawson *et al*. was conceptually quite similar to Hunter's group, with differences being that a 6F steering catheter was placed through an outer 8.5F retrograde catheter to target the desired calyx [8]. After the calyx, soft tissues, and skin were punctured with a 0.017-inch sharpened stylet, a standard PCNL procedure could be performed. The prototype was

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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successfully utilized in all six porcine subjects tested and also in one clinical case. A commercial kit for this technique is available through Cook Medical (Bloomington, IN, USA).

Larger series have reported using these techniques with success rates for access and stone-free status comparable to those for antegrade techniques [6, 9]. Morrisseau and Trotter used the Lawson technique successfully in 69 of 71 procedures and the Hawkins–Hunter technique in the final two patients who had renal scarring [6].The authors used a modified lithotomy position with the ipsilateral upper body elevated 30º with padding. Effective stone treatment was achieved in 86% of patients. The authors did note a significant learning curve, with the first 40 cases lasting 125 min and the final 20 cases only 90 min. In addition, fluoroscopy time averaged 20 min for the first 40 patients and only 5 min for the final 20 patients. One patient required postoperative blood transfusion.

Leal successfully gained access using the Hawkins–Hunter technique in all but one of 85 patients [9]. Stone-free rates were 92% for uncomplicated stones and 68% for more complex stones. Eight patients required postoperative transfusions.

Despite several reports of success with the Lawson and Hawkins–Hunter techniques, there are sparse reports in the literature of their use almost 30 years following their initial description. Drawbacks that have been described include the sometimes indirect route of travel of the needle through subcutaneous soft tissue, the resulting long access tracts created, and difficulty in manipulating the catheter around obstructing stones, through stenotic infundibula, or into the lower pole [4, 10]. Due in part to these limitations and as much owing to the development of small-caliber and effective flexible ureteroscopes, the use of URS-guided retrograde PCNL has become an increasingly described technique at several centers, as will be highlighted throughout the remainder of this chapter.

Indications for retrograde ureteroscopy-guided percutaneous surgery

Indications for the retrograde approach for percutaneous surgery essentially do not differ from the standard indications for percutaneous techniques. The retrograde approach can be used in cases of complex renal stones in addition to less common scenarios such as infundibular stenosis, endopyelotomy, and percutaneous resection of upper tract urothelial cancer [10, 11].

The retrograde approach may be most useful for patients in whom difficult access is proven or suspected (Table 18.1). Prior access failure, obesity, a nondilated collecting system, large and obstructing stone burden, and infundibular stenosis are situations for which retrograde-assisted access may provide higher success rates and prove more efficient.

Table 18.1 Theoretical advantages of retrograde approach.

- Potentially less complicated for patients in whom renal access is difficult:
  - Morbidly obese
  - Challenging anatomy:
    Hypermobile kidney
    Nephroptosis
  - Staghorn or partial staghorn stone
  - Nondilated collecting system
- Provides access to all calyces
  - Multiple percutaneous tracts may be avoided:
    Decreased blood loss
    Decreased risk of pneumothorax
- May decrease fluoroscopy time
- May decrease ureteral migration of stone fragments

Our group has previously demonstrated that multiple percutaneous tracts predict greater blood loss during PCNL [11]. A retrograde approach for treatment and potential repositioning of stones in difficult-to-access calyces can reduce the number of tracts necessary to only the most involved calyx [12]. Marguet *et al*. noted that, using a retrograde technique in seven patients with full or partial staghorn stones, only one tract was necessary with a stone-free rate of 71.4% with minimal residual stone [13]. An additional benefit of the retrograde approach may be reduced fluoroscopy time, although this has not yet been confirmed through comparative analysis [10].

As a result of initial success with these techniques, several groups have documented their use routinely and not just on a selective basis [4, 5]. Nevertheless, greater costs may be involved, especially if a ureteral access sheath is used for retrograde access.

Contraindications

A relative contraindication to percutaneous surgery is urinary infection. All attempts should be made to ensure sterile urine prior to the procedure. Uncorrectable bleeding diathesis is an absolute contraindication to percutaneous surgery. For such patients URS can be considered even if a staged approach is necessary for high-volume stone disease [14]. The retrograde approach is contraindicated in patients with prior urinary diversion with ileal conduit, heterotopic, or orthotopic diversion, and antegrade access with intravenous contrast instillation or ultrasound guidance is preferred.

Preoperative preparation

Proper preoperative imaging includes computed tomography (CT) for comprehensive evaluation of stone size, position, probable composition, degree of hydronephrosis, presence of gas within the collecting system, and surrounding anatomy. Evaluation of the CT characteristics aids in selection of the preferred calyx for access. Presence of severe renal atrophy should prompt acquisition of a radionuclide renal scan to determine differential renal function. If stone size is large and renal function is poor, the option of simple nephrectomy can be entertained. A comprehensive discussion with the patient, including risks, benefits, and alternatives, should be undertaken and consent obtained.

Preoperative laboratory evaluation should include baseline renal function, blood count, platelets, and coagulation factors. A type and screen should also be obtained. Antiplatelet agents should be discontinued at least 7 days prior to the procedure and heparin or low molecular weight heparin can be substituted preoperatively for warfarin. A urine culture should be obtained preoperatively and, if positive, sensitivity-specific antibiotics should be administered. Repeat urine culture should ensure sterile urine. If sterile urine is present, prophylactic antimicrobial coverage should be administered prior to anesthesia and continued perioperatively.

Patient positioning

The patient is initially administered general anesthesia and intubated on the transport cart. The patient is then placed in the prone position on a radiotranslucent table with bilateral chest rolls and preferably equipped with spreader bars for the legs. If spreader bars are not available, the patient's legs can be gently spread during positioning with retrograde access still achievable, though slightly more cumbersome. All pressure points are padded and the flank and genitalia are prepped prior to draping.

Procedure

The instrumentation required for the procedure is listed in Table 18.2 (see Video 18.1). Initially a flexible cystoscope is passed transurethrally and used to place a 0.038-inch hydrophilic glidewire to the ipsilateral renal collecting system. Position is confirmed using fluoroscopy. A 10F Dual-lumen ureteral catheter is then advanced over the glidewire to the mid ureter under fluoroscopic guidance. A retrograde pyelogram using the second port of the catheter defines collecting system anatomy and a second 0.038-inch glidewire is passed through the catheter, thus providing two wires in the ipsilateral ureter. After removing the dual-lumen catheter, an 11.5F outer diameter ureteral access sheath (Flexor, Cook Medical, Bloomington, IN, USA) is advanced under fluoroscopic guidance over the wire to the proximal ureter (Figure 18.1).

Table 18.2 Instrumentation required for retrograde ureteroscopy-guided percutaneous surgery.

Instrument/disposable	Quantity
Flexible cystoscope	1
7.5F flexible ureteroscope	1
27F rigid nephroscope	1
0.038-inch Glidewire	3
Amplatz super-stiff guidewire	1
Cystoscopic camera	1–2
Light cord	1–2
Pressure bag/saline irrigation	1
Video tower	1–2
Nitinol stone basket	1
Holmium:YAG laser	Optional
200-µm holmium laser fiber	Optional
10F Dual-lumen ureteral catheter	1
9.5F/11.5F Cook Flexor ureteral access sheath	1
18G percutaneous access needle	1
8/10F coaxial dilator	1
C-arm fluoroscope	1
30F dilating balloon/nephroscopic sheath	1
Ultrasonic lithotripter	1
Nephroscopic grasping forceps	1
26-cm double-J ureteral stent	1
Nephrostomy tube	Optional

A 7.5F flexible ureteroscope is advanced through the ureteral access sheath into the renal collecting system (Figure 18.2). A pressure bag with saline solution is used for ureteroscopic irrigation. If ureteral stones are noted on preoperative imaging, these can be addressed ureteroscopically using holmium laser lithotripsy followed by advancement of the scope further proximally.

Depending upon the size and distribution of the stone components, several approaches can be taken once the ureteroscope is within the collecting system. If there is significant stone burden outside of the renal pelvis and calyx to be targeted for access, the ureteroscope may be advanced to these peripheral stones and laser lithotripsy can be used to fragment the stones *in situ*. Furthermore, a nitinol basket can be used through the ureteroscope to reposition the stones in an accessible area for the ensuing nephroscopy. In cases of infundibular stenosis, laser infundibulotomy is used to gain access to the dilated calyx.

When no further ureteroscopic intervention is desired, the ureteroscope is advanced to the calyx to be targeted for access (Figure 18.3). Under direct ureteroscopic as well as fluoroscopic guidance, a disposable 18G access needle is advanced percutaneously into the calyx of choice (Figure 18.4). Our technique for access involves targeting the preferred site in anteroposterior as well as oblique planes. Needle placement is confirmed ureteroscopically and a 0.038-inch glidewire is advanced into the calyx.

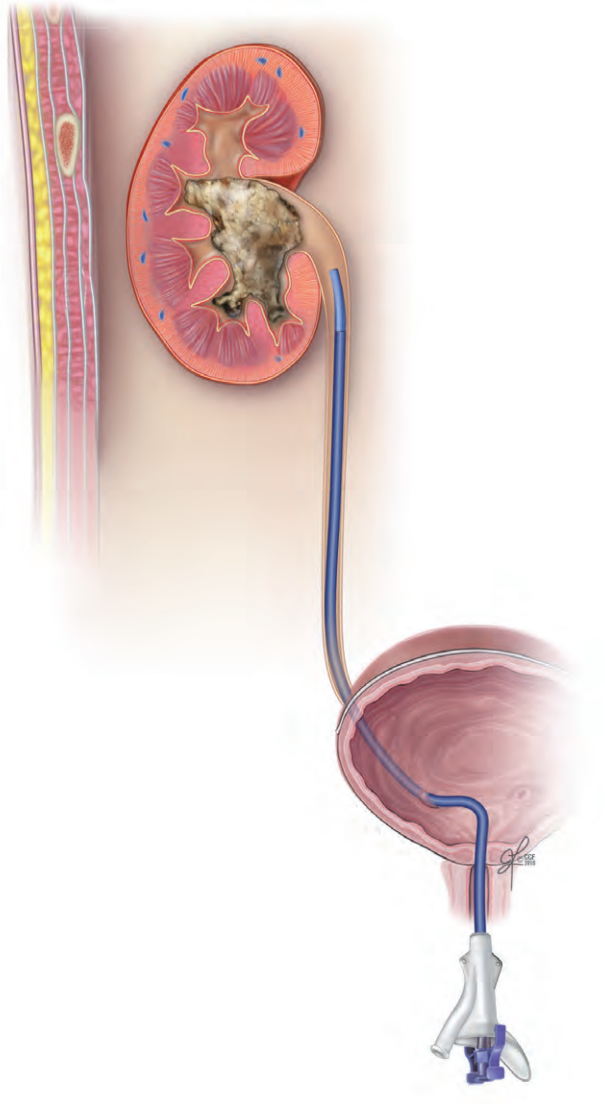

Figure 18.1 Positioning of ureteral access sheath (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

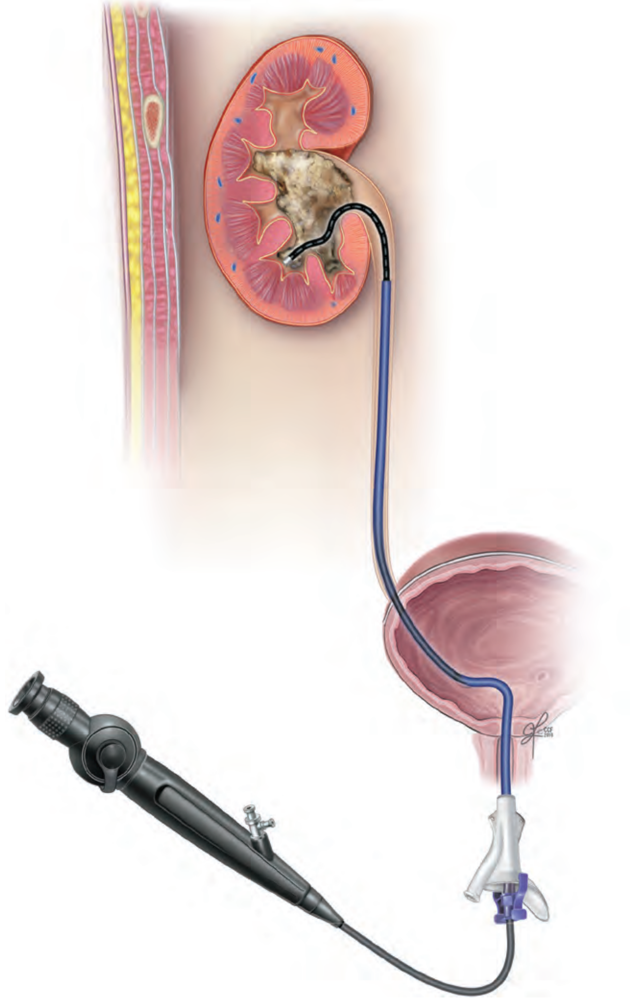

Figure 18.2 Positioning of ureteroscope (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

Upon identification of the wire, a nitinol stone basket is advanced through the ureteroscope, and used to grasp the wire and bring it down through the access sheath and out of the urethra for through-and-through access (Figure 18.5). If the wire is dropped by the basket within the access sheath, it usually can be advanced easily in the antegrade direction by simply pushing the wire through the access needle.

At this point the skin is incised sharply and amply around the cutaneous entry point, and the access needle is removed. An 8/10F coaxial dilator is then passed over the percutaneous wire to the proximal ureter and used to place an Amplatz super-stiff guidewire as a second wire. A 30F dilating balloon with a 30F nephroscopic sheath backloaded is then advanced into the collecting system, and used to dilate and place a nephroscopic sheath (Figure 18.6).

A 27F rigid nephroscope is then advanced into the collecting system and the stones are treated with a combination of ultrasonic lithotripsy as well as intact fragment removal (Figure 18.7). Flexible URS can be used during or following nephroscopy in order to aid in lithotripsy as well as ensure stone-free status in difficult-to-access calyces. This may limit the number of access tracts needed.

Following PCNL a 0.038-inch glidewire may be placed either in an antegrade or retrograde manner through the nephroscope and down the ureter. The access sheath is removed, the distal portion of the wire is curled in the bladder, and a 26-cm double-J ureteral stent is advanced through the nephroscope and positioned appropriately.

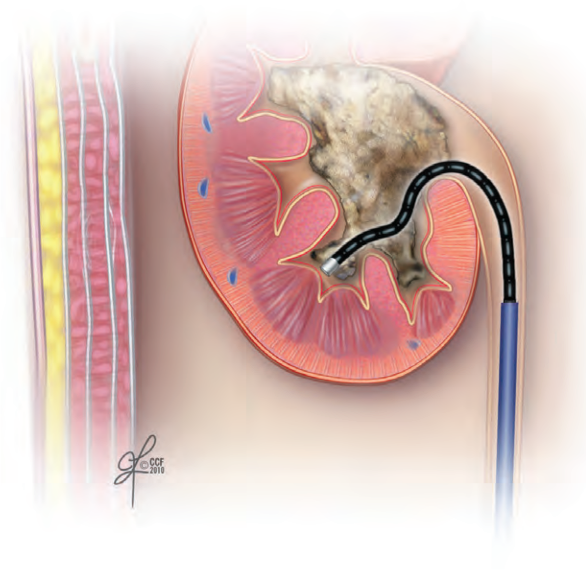

Figure 18.3 Ureteroscopic visualization of targeted calyx (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

Depending upon the ease of the procedure as well as the confidence in a stone-free status, a nephrostomy tube can be placed.

Special considerations

One of the greatest challenges when using the retrograde approach is the need to perform retrograde endoscopy in the prone position. Supine PCNL as originally described by Valdivia (see Chapter 10) will place the patient in a more familiar position for urologists to perform retrograde maneuvers [15]. Furthermore, the Galdakao-modified Valdivia position allows the patient's legs to be strategically placed within stirrups to provide even greater access with a retrograde technique [16]. Scoffone *et al*. described their experience with 127 patients using the Galdakao-modified Valdivia position [5]. The stone-free rate was 81.9% with an average operative time of only 70 min, and 98.4% of patients required only one percutaneous tract. The authors site many potential advantages of the supine approach besides easier retrograde access, including anesthesia considerations and likely decreased fluoroscopy exposure.

Postoperative care

Directly postoperatively, routine labwork, including hemoglobin, is obtained and a chest X-ray is performed, especially in cases of supracostal access. We routinely obtain a noncontrast CT 1 day postoperatively in order to assess for residual stones. If stones are present, it is dependent on the patient's and clinician's preference whether an immediate second-look procedure is performed, especially if a nephrostomy tube has been left, or whether a delayed ureteroscopy is chosen. After performing the retrograde technique, our preference is to leave the double-J stent for approximately 1 week and then to remove the stent using flexible cystoscopy in the outpatient clinic. Warfarin or antiplatelet therapy may be resumed as early as 5 days following surgery if necessary [17].

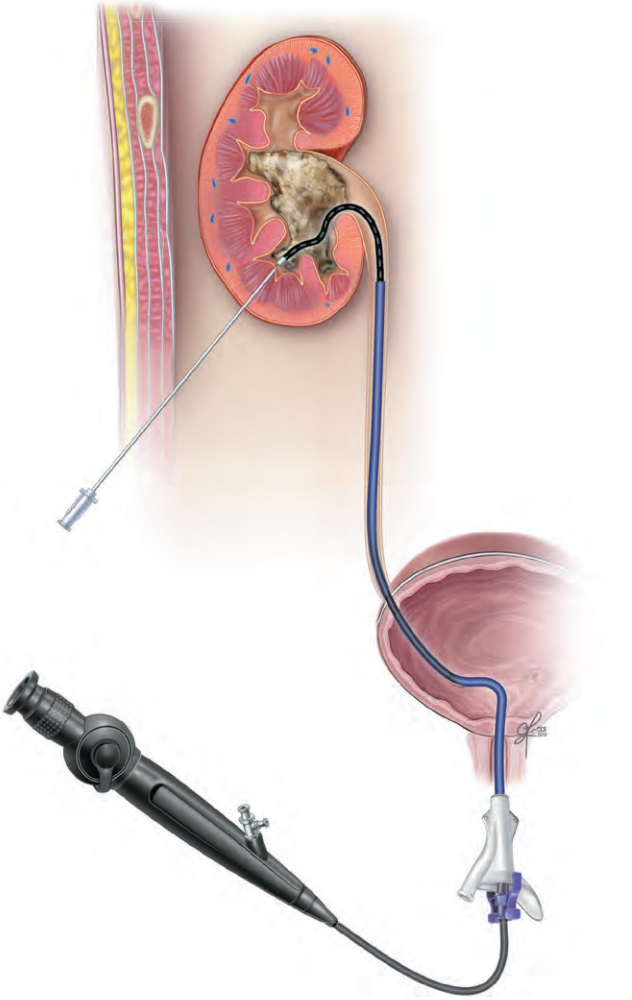

Figure 18.4 Access needle puncture under ureteroscopic guidance (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

Outcomes

Results in the literature concerning retrograde URS-guided percutaneous surgery are summarized in Table 18.3 [4, 5, 10, 13, 18, 19]. Over the last 15 years several series have been published with most describing small

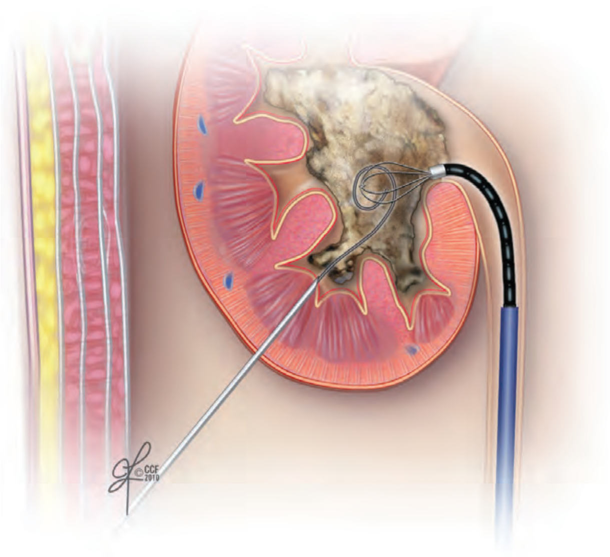

Figure 18.5 Passage of a glidewire via the access needle with basket retrieval using the ureteroscope (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

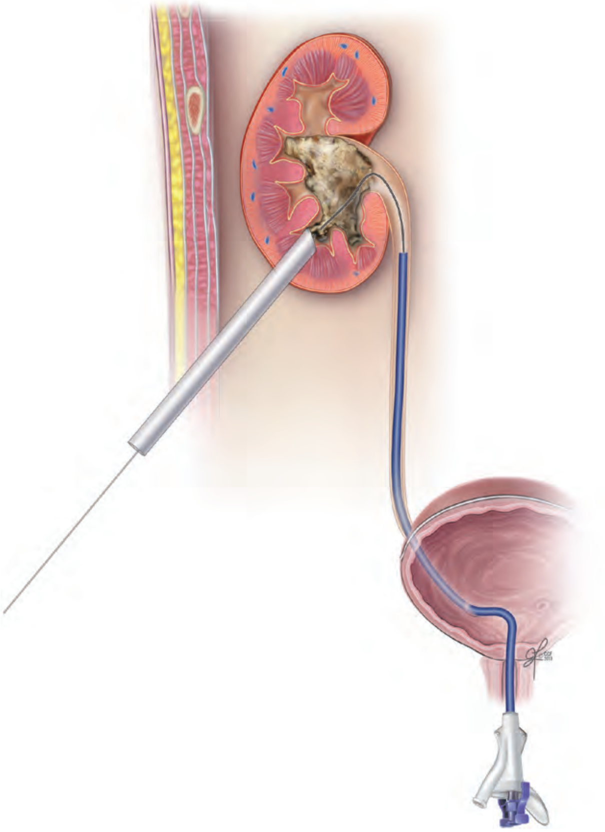

Figure 18.6 Positioning of the nephroscopic sheath (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

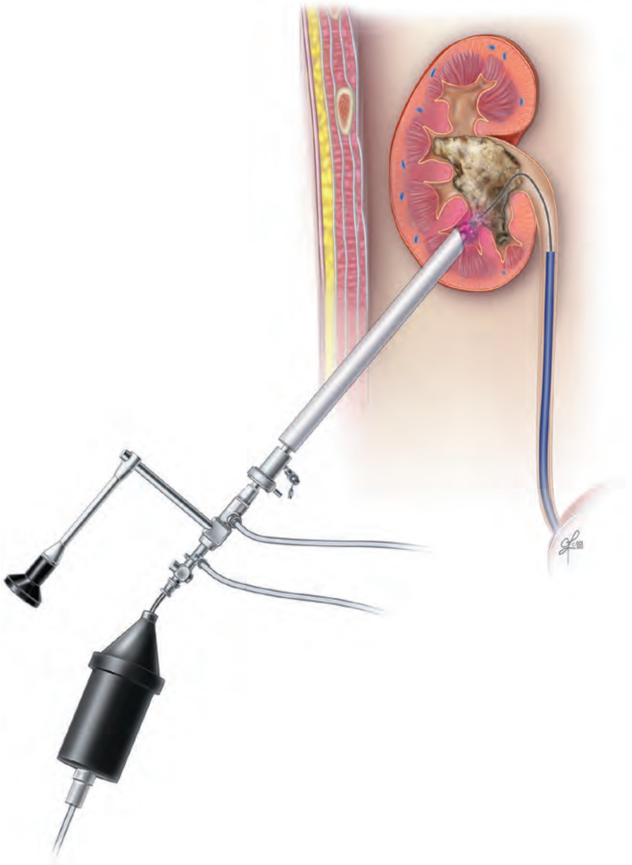

Figure 18.7 Nephrolithripsy (reproduced courtesy of the Cleveland Clinic Center for Medical Art & Photography © 2010. All rights reserved).

numbers of subjects. Overall stone-free rates, 63.6–100%, are comparable to series using a purely antegrade technique. Remarkably, very few cases requiring multiple access tracts have been described despite a complex patient population with a large proportion having partial or complete staghorn stones.

Perhaps owing to the limited number of access tracts and reasonable operative times of 70–186 min, complication rates and specifically transfusion rates have been low, with most small series reporting no or one transfusions, and the largest series of 127 patients reporting four cases of transfusion (notably though three of these patients required angioembolization) [5]. Though some reports mention benefits of decreased fluoroscopy time with these techniques, little detail or comparative analysis exists as yet to support this claim.

Despite the fact that the retrograde techniques likely have advantages over an exclusively antegrade approach in certain situations, no prospective or even retrospective comparisons exist to better define its role. Nevertheless, endoscopic technology is continuously evolving and it can be predicted that the role of retrograde assistance and treatment may further expand.

Table 18.3 Case series using ureteroscopy for combined antegrade and retrograde approach to percutaneous nephrolithotomy.

Study	No. of cases	Operative time (min)	Fluoroscopy time	Complications	Stone-free rate after primary treatment (%)	Estimated blood loss (mL)	Miscellaneous
Grasso *et al.* 1995 [10]	7 (3 patients with stones in caliceal diverticula)	N/A (<30 min for access in all cases)	N/A	none	N/A	N/A	For cases with caliceal diverticula, the stenotic infundibulum was dilated with a ureteroscopically introduced balloon to 12F
Kidd and Conlin 2003 [18]	3	N/A	N/A	None	100	N/A	Used selectively for obese patients; patients with hypermobile, ptotic kidney; and patients with complete staghorn stone
Landman *et al.* 2003 [19]	9 total (6 complete staghorn 3 partial staghorn)	186	N/A	4 (atelectasis, ipsilateral leg paresthesia, pulled intercostal muscle, 4-cm perirenal hematoma)	78	290	All patients had one lower pole tract No transfusions
Marguet *et al.* 2005 [13]	7 complex or staghorn stones	142	N/A	None	71.4 (3 and 2 mm residual stones)	79	Single session: ureteroscopy performed in prone position followed by standard prone PCNL. All patients had one tract
Khan *et al.* 2006 [4]	11 for stones (1 case for endopyelotomy and percutaneous nephropexy)	N/A	N/A	Transfusion	63.6 (twosecondary procedures)	N/A	Technique used routinely (not selectively for complex stones or in cases of prior access failure) All patients had one lower pole tract At end of procedure 4 patients with 10F Cope Loop nephrostomy, remainder tubeless All patients had JJ stent placed
Scoffone *et al.* 2008 [5]	127	70, including positioning	N/A	38.6% overall Transfusion: 4 patients Angioembolization for arteriovenous fistula: 3 patients JJ stenting for urinary fistula: 5 patients	81.9	N/A	All cases performed in Galdakao-modified supine Valdivia (GMSV) position Technique used routinely (not selectively for complex stones or in cases of prior access failure) 98.4% of cases with single access tract, majority lower pole access At end of procedure all pts. left with nephrostomy tube 59.9% left with double-J stent

Conclusions

The retrograde technique for percutaneous surgery can provide several advantages over an exclusively antegrade approach, especially in cases in which percutaneous access is difficult. Issues of cost and equipment availability, as well as an undefined degree of benefit, limit our ability to recommend a retrograde approach routinely for all percutaneous cases.

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CHAPTER 19

Percutaneous Renal Surgery Selection of Access: Robotic

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Introduction

Since the latter part of the 20th century, robotic technology has been applied to a number of industrial and manufacturing processes. Due in great part to potential advantages of motion finesse associated with robotic manipulation, recent years have witnessed an increased interest in the introduction of robotics to the healthcare system. Robots were first introduced to the surgical field in the 1980s, and at that time were focused primarily on neurosurgical and orthopedic applications [1]. As interest in robotics expanded into other medical specialties, urologic applications were soon identified. Since that time, robotics has rapidly assumed an integral role in the urologic armamentarium.

The first reported urologic application of robotic technology was described by Davies *et al*. in 1989, who designed a robot (PROBOT) to perform transurethral resection of the prostate [2–4]. Since that time, a number of targeted research projects have been undertaken to identify and develop applications for robotics within the urologic specialty. In many cases, robotic-assisted surgical approaches have become commonly accepted; robotic-assisted laparoscopic radical prostatectomy may be the best example of this.

The suitability of robotics for urologic surgical applications derives from the properties inherent to robotic technology; namely that these devices are versatile, mechanically capable, and programmable. Tasks that are particularly suited to robotic technology are those that require accuracy, reproducibility, fine motor movements, as well as motion that is difficult to perform by hand due to constrained access, such as for laparoscopy, and ergonomic limitations, such as for magnetic resonance imaging (MRI)-guided interventions. To that end, robotic technology can improve on conventional techniques in, for example, securing percutaneous access to the renal collecting system. In this chapter we will review the genesis and present applications of robotic systems designed to facilitate percutaneous renal access.

Goals of robotic percutaneous renal access

Urology has been one of the surgical disciplines at the forefront of the application of robotic technology, and the kidney is rapidly becoming a target organ for this technology. Robotic-assisted laparoscopic renal surgery, although only recently described, is becoming a standard surgical approach for renal malignancy and reconstruction. Image-guided percutaneous surgery is likely to be the next generation of renal surgery to benefit from robotic technology [5]. Percutaneous renal surgery encompasses a wide diversity of procedures: nephrostomy tube placement, percutaneous nephrolithotomy (PCNL), percutaneous treatment of transitional cell carcinoma, renal biopsy, radiofrequency ablation of renal tumors, and percutaneous renal tumor cryoablation. These many procedures are all potential clinical applications for a robot designed to gain renal access percutaneously.

There are a number of practical advantages to robotic assistance for percutaneous renal therapies. For the urologist, one of the most significant challenges of a percutaneous procedure is applying the three-dimensional (3D) renal anatomy to a two-dimensional

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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image representation. In many cases, this anatomic transposition may be confusing. Reliably and safely attaining an optimal point of renal access can require extensive training and experience. Certain clinical situations, such as entry into a nondilated renal collecting system, can be challenging, even for the experienced clinician. An additional complexity for the urologist, which is not encountered in the orthopedic and neurosurgical fields, is the mobility of the kidney within the retroperitoneum, including its continuous movement with respirations. At many institutions, urologists lack the requisite experience in placing percutaneous access, and such procedures are performed by the interventional radiologist. A lack of participation by the urologist in obtaining percutaneous access for PCNL, for example, may result in the patient undergoing more than one procedure if the access and nephrolithotomy portions of the procedure are performed at times and locations remote from one another. The urologist may also have insights into the manner in which stone removal should be performed, and a lack of such input may result in suboptimal access location. Additionally, there are certain complex clinical scenarios where multiple access sites may be necessary, thus requiring further procedures.

Unlike humans, robots are digital devices that are controlled in 3D space. With proper image registration and navigation algorithms, these can be used to address many of the challenges associated with renal access: improved spatial accuracy, programmable, mechanical, and flexible capabilities, and once designed they can be reproducibly used by a surgical novice. With novel technology that allows constant impedance measurements and rotating needle drivers, many of the abovementioned challenges, such as renal mobility, could possibly be overcome.

The ultimate goals in applying robotic technology to percutaneous access are to increase the ease and decrease the technical challenges of this task, while improving accuracy, efficiency, and reproducibility. Robotic technology holds the potential to provide greater precision than the human hand can, with improved puncture accuracy. Robotic assistance for percutaneous access may ultimately improve surgical performance, and decrease complication rates and operative times [6].

Development and evolution of robotic percutaneous renal access systems

Robotic percutaneous renal access systems were first proposed less than two decades ago by Potamianos *et al.*, who performed pioneering work in the creation of a passive robot to facilitate needle placement for percutaneous surgery [7–9]. The system was mounted on an operating room table, required fluoroscopic imaging to guide placement, and had five degrees of freedom (DOF). System performance experiments reported at that time described a 1.5-mm targeting accuracy.

In 1996 our urology engineering program, URobotics, was initiated at Johns Hopkins Medicine [10]. This program is dedicated to the development of new technology and gathers both clinical and technical personnel working in close communication to achieve the goal of robotic image-guided surgery. Many of the robotic systems that have been developed over the last 15 years were developed through this program; these systems will be discussed below.

Modified LARS

A prototype system using a modified Laparoscopic Assistant Robotic System (LARS) was introduced in 1997 by Cadeddu *et al*. [9]. LARS was a modified laparoscopic assistant active robotic system which maintained seven DOF. Each robotic joint was moved by an electric motor, so the access procedure was totally automated. Biplanar fluoroscopic imaging was used to guide the access procedure. The authors described that *in vitro* accuracy was 0.43 mm, and *ex vivo* success with the first attempt was 83%. The authors noted that problems arose with tissue and needle deflection. No comparison to nonrobotic human placement was done with this device, but rather this was a proof-of-concept experiment. This study, despite its limitations, demonstrated that robotic percutaneous access was feasible, although the need for multiple improvements and modifications, such as advanced software, increased DOF, and improved needle design and feedback mechanisms, were identified.

PAKY

The next generation of robotic systems that was developed for renal indications was termed PAKY (which stood for percutaneous access to the kidney), and also is a product of the URobotics program at Johns Hopkins. PAKY consists of a passive mechanical arm with active translational motion providing needle insertion in a compact and radiolucent module. The device is mounted on an operating room table and can be fitted with a standard trocar needle. An active translational mechanism is used for needle advancement, and fluoroscopy is used to align and monitor needle placement. *In vitro* experiments using PAKY were carried out in 1998 with porcine kidneys and *in vivo* studies were completed in nine human patients [11]. Accuracy was 100% in both *in vitro* and *in vivo* attempts. The mean targeted calyx was 14.7 mm in diameter, and the mean time required to gain access was 8.2 min. No complications occurred in any of the trials. These *in vivo* studies demonstrated the robotic system to be steady, safe, and effective, thus serving as a springboard and providing the groundwork for further development of a complete robotic system.

PAKY-RCM

In 2002 the second-generation PAKY robot, PAKY-RCM (percutaneous access to the kidney with the remote center of motion device), was also introduced by the URobotics program. This is a robot with three active DOF that can remotely align the needle along a selected trajectory pathway under fluoroscopic guidance, minimizing radiation to the surgeon's hands. PAKY is the needle driver and the RCM device is an active robotic arm attached to PAKY that allows the tip of the needle to pivot about a fixed point on the skin. There is a joystick control located on the control box used to advance the needle. Clinical comparison was done using PAKY-RCM versus manual needle placement [12]. There were 23 patients per group and variables measured were number of access attempts, time to successful access, estimated blood loss, and complications. In the robotic group, 87% (20 of 23) of attempts were successful in gaining access. Three patients were converted to manual techniques for various reasons including mechanical failure, and these were successful but took longer than 30 min, illustrating the complexity of the access. All manual access attempts were successful. Only single access was needed for all patients, and no major complications occurred in either group. Time to access was not significantly different between the groups ($P = .06$), with a mean of 10.4 min required for robotic access versus 15.1 min needed for manual access. These investigators again demonstrated the robotic access to be both feasible and safe, with acceptable success rates.

Electrical impedance needle sensor

Entry into the renal collecting system is the requisite endpoint of percutaneous renal access. However, in many cases the urologist has little objective data to confirm this outcome; radiographic imaging can be uncertain and aspiration of urine can be unreliable. To address this clinical problem, the URobotics program designed a "Smart Needle" system, which consists of an access needle fitted with a sensor on the exposed stylet tip that continuously measures electrical impedance (Figure 19.1) [13]. When the collecting system is entered, resistivity drops precipitously. This system was invented to provide objective feedback to the surgeon that access into the renal collecting system has been successfully gained; malpositioning of the needle should be reduced with this device. A series of experiments in which image-guided access to porcine kidneys was performed revealed a significant reduction in resistivity when the needle entered the collecting system in 11 of 16 attempts. The promise of the Smart Needle system rests in its ability to optimize renal access, potentially reducing needle-related complications which may occur during this procedure. This needle, which can provide objective feedback to the surgeon gaining access, may reduce the number of access attempts, increase puncture accuracy, and decrease procedure duration. The Smart Needle can be used in combination with any of the previously described robotic systems. It should be noted that the Smart Needle was evaluated only in dilated collecting systems and it is unclear if impedance will drop so precipitously in a nondistended system. In addition, urine with altered chemical make-up, such as grossly bloody or purulent urine, may not demonstrate such an objective reduction in resistivity. Further studies are required to better define these potential limitations.

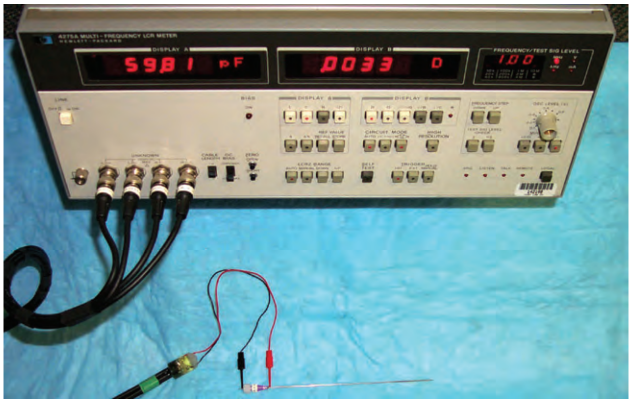

Figure 19.1 Electrical impedance system for the "Smart Needle."

AcuBot robot

Needle-based therapies such as thermal ablation are increasingly being utilized for the treatment of renal tumors. Due to the image-guided nature of these procedures, there is interest in the design of computer-assisted navigational systems to increase treatment accuracy. AcuBot is a novel, completely automated, robotic system with six DOF capable of needle placement based on imaging data (Figure 19.2). It has the advantage of changing skin locations for entry and has force sensors. Studies have been conducted in phantom models with computed tomography (CT)-guided imaging to assess and compare accuracy between robotic and manual placement by experienced surgeons and radiologists [14]. Accuracy was 1.2 mm for AcuBot needle placement versus 5.8 mm in manual placement ($P < .0001$). The mean time from target acquisition to needle placement was 37 s for the AcuBot and 108 s for the surgeon

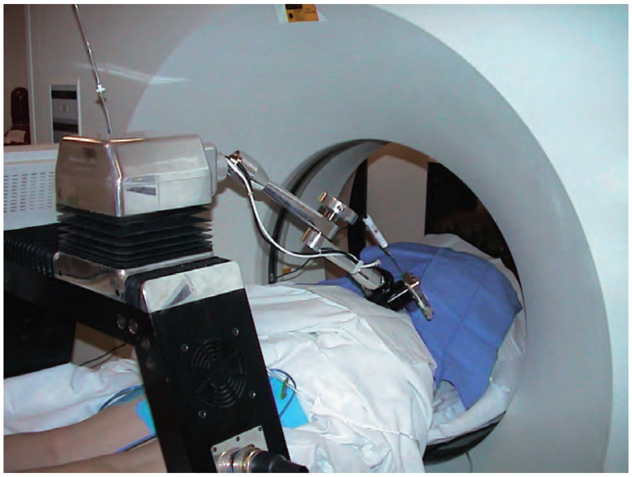

Figure 19.2 Clinical demonstration of Acubot robot.

(*P* = .001). This robotic system has the potential to increase both accuracy and operative time, thus decreasing complications and improving clinical outcome. Further studies in animals and clinical experiments are needed to better characterize this promising technology.

Revolving needle driver

Most image-guided robots position and orient a needle guide so that the needle is manually placed through the guide [15]. There are advantages in manually inserting the needle through a guide, such as keeping the physician in direct control of the needle, instrument simplicity, and perhaps facilitating regulatory approvals for clinical trials and use. However, this compromise also mediates the full potential benefits of robotic image guidance [16, 17]. The Johns Hopkins URobotics group has recently developed a tow-DOF needle driver that, in addition to automated insertion, can spin the needle and perform a set of experiments to assess the influence of needle spinning on the accuracy of needle insertion (see Video 19.1) [18]. Figure 19.3 shows the revolving needle driver device supported by the AcuBot robot. Experiments revealed that spinning is useful for improved targeting and could reduce errors by as much as 70%.

Telerobotics and telementoring

Telemedicine has emerged as a promising new field, and provides the ability to disseminate surgical knowledge, particularly complex techniques, to novice surgeons. Both AESOP (robot for remote manipulation of endoscopic camera) and PAKY (percutaneous access of the kidney) have been used to study the utility and feasibility of telesurgery and international mentoring [19, 20]. Among the procedures completed were renal biopsy and percutaneous access to perform nephrolithotripsy or place a nephrostomy tube, which was successfully achieved with PAKY [21].

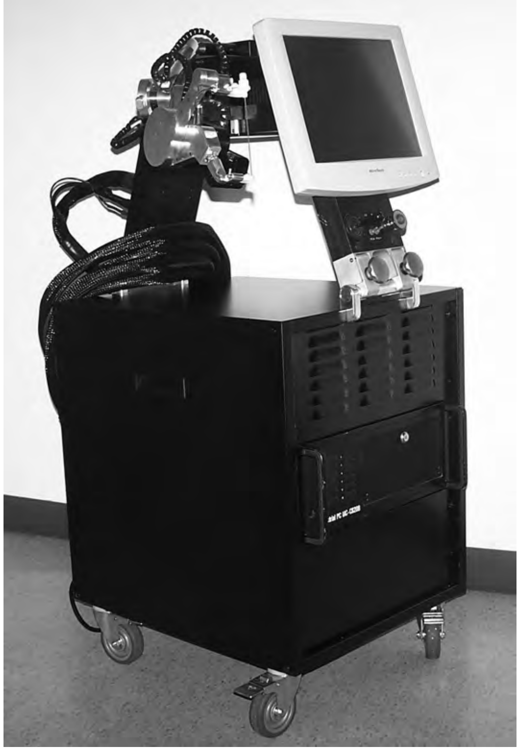

Figure 19.3 Acubot robot with revolving needle driver.

Telesurgery has been the subject of a randomized control trial, which compared human versus robotic and telerobotic access to the kidney. Using a validated kidney model, the authors found that in over 304 access procedures, humans were faster than the robot (35 s versus 57 s). The robot, however, was more accurate with 88% success of access gained on the first attempt versus 79% success by humans (*P* = .046) [22].

The future

Although much of robotic percutaneous access remains investigational, several systems have been tested and applied to clinical situations with human patients. Several of these systems, as described above, have demonstrated great promise in improving safety, accuracy, and clinical outcomes, while decreasing operative times and complication rates. If these goals are achieved, robotic systems have the potential to be both cost-effective as well as medically desirable. Importantly, in the present medical climate, the cost-effectiveness of these systems must be considered, an area of research that remains to be done. However, as time passes and technology continues to be refined, it is anticipated that robots will play ever increasing roles in precise and accurate techniques such as those required for percutaneous access.

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CHAPTER 20

Dilation of the Nephrostomy Tract

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Introduction

Following creation of percutaneous renal access, tract dilation is an essential step in the performance of percutaneous renal surgery. With proper tract dilation, an appropriate size working sheath can then be placed, facilitating the insertion of the endoscopes, working instruments, and nephrostomy tube.

Dilation of the tract can be achieved in several ways. Use of fascial dilators, Amplatz dilators, metal coaxial dilators, high-pressure balloon dilators, and radially expanding single-step nephrostomy dilators is well described. In this chapter, the features of each dilation modality and their application will be reviewed.

Technique

Regardless of the instrumentation used in tract dilation, there are several technical steps common to each modality. Dilation of the nephrostomy tract follows percutaneous needle puncture into the calyx of interest. The correct placement of the needle is mandatory, as the path of the puncture needle determines which structures are punctured and subsequently dilated. Dilation is always performed over a guidewire. Ideally this wire should be a 0.035 or 0.038 inch extra- or super-stiff variety to minimize the risk of wire bending or kinking. Whenever possible the guidewire should be advanced into the bladder – the additional length of guidewire within the body reduces the chance of inadvertent wire displacement and tract loss during subsequent manipulations. If this is impossible, enough wire should be coiled within the renal pelvis such that the transition point, where the floppy tip and stiff portions meet, is well within the collecting system [1]. Image guidance is essential during tract dilation. Once the super-stiff wire is placed correctly, a 1.5–2-cm skin incision is made around the wire. The dilating instrument is then advanced over the guidewire.

Instrumentation

Fascial dilator systems

The fascial dilator system set is composed of Teflon cylindrical dilators of progressively larger circumference, ranging from 5F to 30F in size (Figure 20.1). Each dilator is designed to be introduced over a 0.038-inch guidewire. The introduction of each dilator is usually carried out in a rotational or spinning motion, under mandatory fluoroscopic guidance.

This system is particularly useful when faced with the need to dilate a heavily scarred tract, following previous percutaneous surgery or in the presence of a retroperitoneal inflammatory process [2]. The main disadvantage of this system is its reliance on the guidewire stability, with potential risk of guidewire kinking leading to dilation failure. This risk tends to be exaggerated with increased length of tract, such as in obese patients. Additional theoretical concern is the application of excessive manual force during the tract dilation, leading to perforation of the medial wall of the renal pelvis, and renal laceration and bleeding [3].

Amplatz dilator system

The Amplatz dilator system, also known as the malleable dilator system, was developed in 1982 by Kurt

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Amplatz to address some of the previously identified disadvantages of the fascial dilator system (Figure 20.2). The set is composed of tapered-tip polyurethane cylindrical dilators, of progressively increasing circumference, ranging from 8F to 30F. The main advantage of this system is conferred by the use of a tapered 8F angiographic catheter. The use of the angiographic catheter provides additional stiffening and stability to the guidewire, thereby decreasing the risk of guidewire kinking.

The 8F angiographic catheter is inserted over the guidewire under fluoroscopic guidance, as an initial step. All subsequent larger dilators are inserted over the 8F catheter and guidewire, in order of increasing diameter. Advancement of each dilator is best accomplished using an alternating clockwise–counterclockwise rotational motion to minimize the chances of guidewire kinking. The shoulders of each Amplatz dilator must be advanced until entirely within the entry calyx. The working sheath is introduced last, over the largest Amplatz dilator until the leading edge of the sheath overlaps the shoulders of the Amplatz dilator (see Video 20.1).

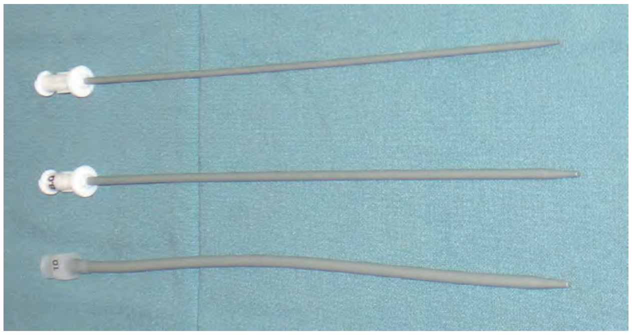

Figure 20.1 Fascial dilators.

An additional advantage of this system is offered by the relative rigidity of the dilators, which in combination with the increased stability and tapered profile, allows greater freedom in dilation of the scarred retroperitoneum. As in the previous system, the main disadvantage is still the theoretical risk of excessive application of force, leading to renal pelvis perforation and renal parenchymal bleeding [2, 3].

Coaxial metal dilator systems

Coaxial metal dilator systems, such as the Alken or Lunderquist instruments (Figure 20. 3), are composed of stainless steel rods which are mounted together in a telescopic fashion. Each dilator is designed to adapt to the lumen of the next successive dilator, starting with an 8F hollow guide rod. The initial hollow guide rod is advanced over a guidewire under fluoroscopy, until its tip is positioned within the renal pelvis. Dilation is achieved with six successive dilators, each increasing in size by 4F, ultimately dilating the tract to either 24F or 26F. A metal guard at the end of each rod represents the endpoint for the insertion of the dilator [4, 5]. The main advantage of this system lies in its rigidity, which provides support for dilating through dense scar tissue. This advantage is offset by increased potential for iatrogenic injury, due to difficulty with controlling the pressure during dilation. Moreover, the necessity for manual stabilization of the central rod during the dilation increases the risk of perforating the renal pelvis.

Modification of the standard Alken metal dilators has been described in an attempt to improve the safety margin [6]. The dilators were modified to become

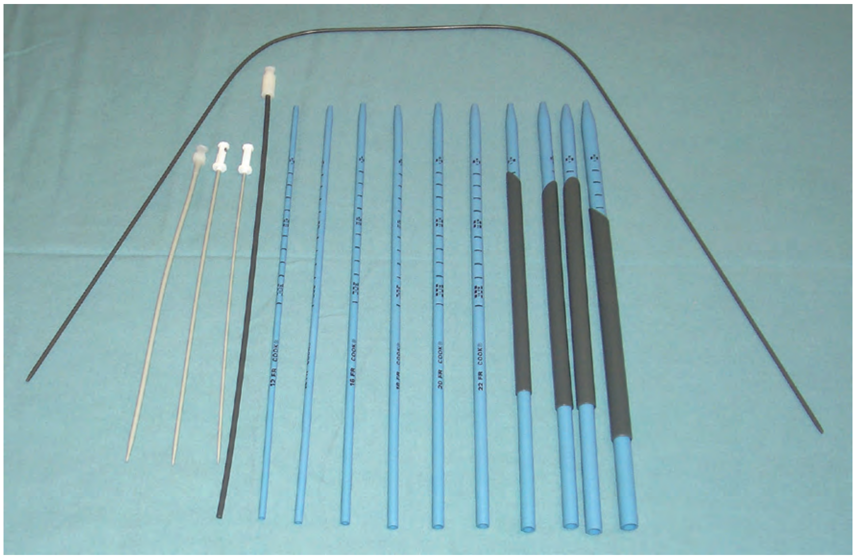

Figure 20.2 Amplatz dilators.

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Figure 20.3 Alken metal dilator with guidewire in the rods (A) partially advanced and (B) fully advanced (reprinted from Seemann, O., Alken, P. Dilation of the nephrostomy tract – use of metal dilators. In: Smith, A., ed. *Controversies in Endourology.* Philadelphia: WB Saunders, 1995, pp. 42–49, with permission of Elsevier).

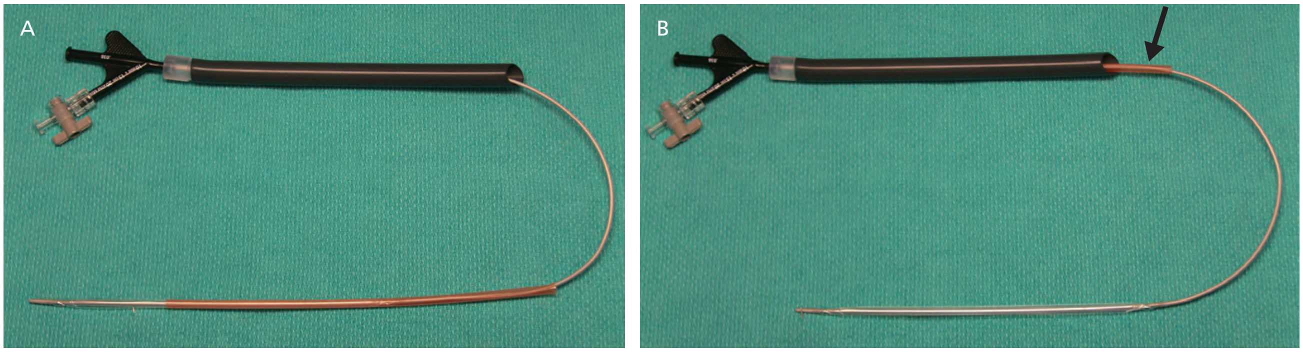

Figure 20.4 Balloon dilator (A) with protective sheath and (B) with protective sheath retained to aid in complete balloon deflation should additional tract(s) be required.

tapered, shorter, nonlocking, thinner, and with centimeter markers on the surface. These modifications have been shown to decrease trauma to the tissues and reduce the chance of renal pelvis perforation from overadvancing the dilators. Additionally, the nonlocking mechanism allows for removal of inner dilators, allowing insertion of a ureteroscope and inspection of the tract and collecting system as the tract is being established [6].

Balloon dilator systems

The use of balloon dilators was pioneered in the field of interventional angiography and has subsequently been adapted for use in other disciplines. The application of balloon dilation to percutaneous renal surgery has been a major advancement.

Percutaneous nephrostomy tract balloon dilators are intended for creation of tracts in a rapid, single step, eliminating the need for serial dilation. They are designed to be introduced into the collecting system over a guidewire and tract dilation is carried out under fluoroscopic guidance. The balloon dilator set consists of an expandable balloon, 30F working sheath that is back-loaded before the deflated balloon is placed over the wire, and syringe inflator (Figure 20.4A). Pressures of up to 20 atm can be easily achieved with this system, although in general, much lower pressures are usually sufficient for tract creation. Balloon inflation allows for full expansion of the balloon, which is followed by insertion of a working sheath over the balloon, in a rotational manner.

The main advantage of the balloon dilation technology lies in the fact that the tract is created using lateral, rather than angular, shearing forces. In theory, lateral forces are less traumatic and reduce the chance of large vessel injury and resultant hemorrhage. An additional advantage is the elimination of serial dilation, which saves operating room time [7]. The dilation is also more controlled, as the balloon can easily be stabilized during the inflation. In earlier experience, the use of balloon dilators was found to result in a lower rate of blood transfusions in comparison to Amplatz and fascial dilators [8, 9]. Contemporary series comparing the Amplatz and balloon dilation systems have suggested the differences in complications may not be significant [10, 11].

The main disadvantage of balloon dilators are their relative higher cost compared to the other systems. The balloons are designed for single use only, further adding to their expense. In a case where more than one tract is required, the same balloon can be used again. To do this requires complete deflation of the balloon of all contrast such that there are no wrinkles in the balloon profile. This can be achieved by using the protective sheath that covers the balloon when the package is first opened (Figure 20.4A). Rather than removing this protective sheath, we have found it easier simply to slide it away from the balloon segment, but keeping it on the catheter. The protective sheath can then be pulled back over the balloon portion should the surgeon need to use the balloon again in the same case to dilate an additional tract(s) (Figure 20.4B).

Other concerns with the balloon catheters include an inability on occasion to dilate through dense scar tissue and the risk of balloon rupture causing barotrauma.

In most situations, the balloon dilator is advanced until the proximal radio-opaque marker is positioned within the entry calyx (see Video 20.2). Correct placement of the balloon dilator is essential to provide a useful tract and to avoid significant bleeding. To aid in proper placement, retrograde contrast injection via the previously placed ureteral catheter will delineate the collecting system. The balloon should not be inflated within the infundibulum to avoid potentially significant hemorrhage (see Video 20.2). It should also be mentioned that with most of the balloon dilators on the market, a short segment of balloon extends beyond the proximal radio-opaque marker. The features of the balloon being used must, therefore, be understood so this can be compensated for when placing the balloon into the entry calyx, to avoid over dilation.

Balloon inflation is performed using radiographic contrast instilled within the injector syringe. The balloon should be inflated until no "waisting" or focal narrowing is evident (Figure 20.5). The pressure required to dilate the tract is generally under 15 cmH_2O. The balloon dilator should be manually stabilized during this procedure in order to avoid inadvertent displacement. Next, a 30F working sheath is advanced over the inflated balloon. This maneuver is facilitated by slowly advancing the sheath while rotating it over the balloon, under fluoroscopic guidance (see Video 20.2). Care should be taken while the sheath is being advanced that the balloon does not advance into the renal pelvis. The

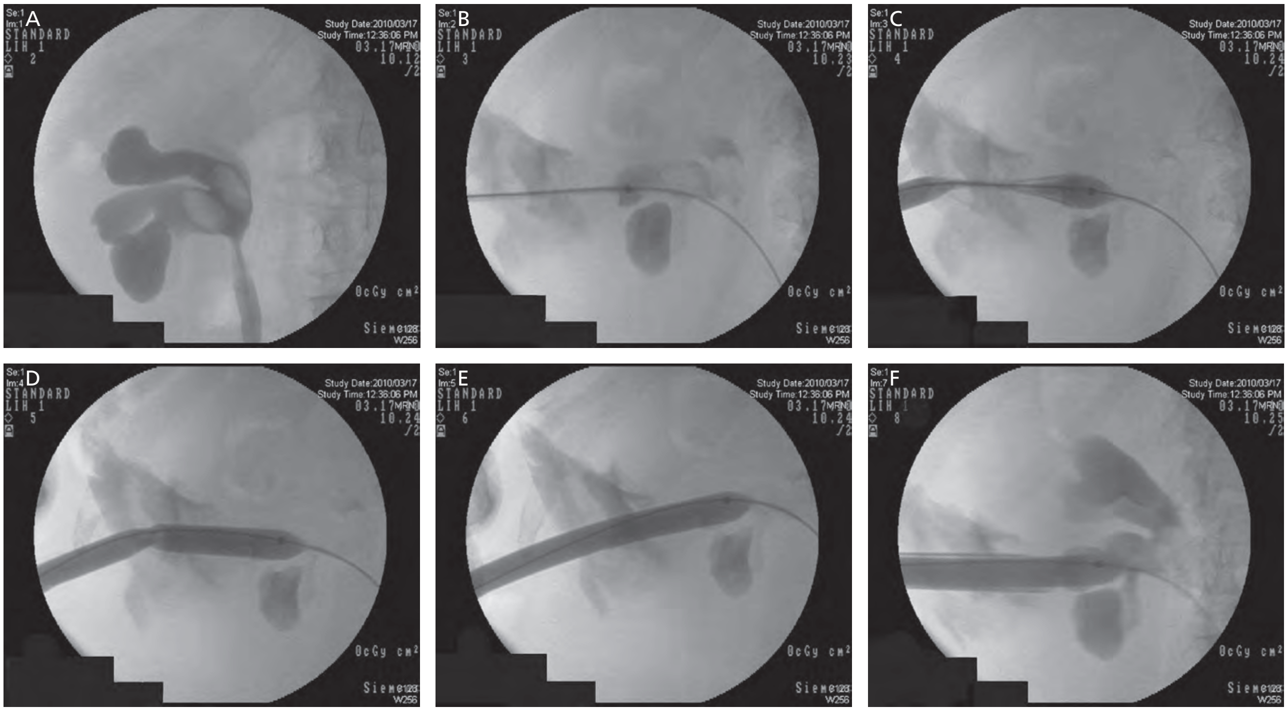

Figure 20.5 Nephrostomy tract dilation with balloon dilator: (A) retrograde pyelogram obtained prior to needle puncture; (B) insertion of a deflated balloon dilator over the super-stiff wire; (C) initial inflation of the balloon dilator; (D) typical "waist" seen towards the end of tract dilation; (E) fully inflated balloon with full tract dilation; (F) insertion of 30F working sheath over the inflated balloon.

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Figure 20.6 Radially expanding single-step nephrostomy (RESN) dilator. (A) 8F woven sleeve with an inner stylet, a 30F tapered fascial dilator, and an Amplatz-like working sheath. (B) Inner stylet placed in the woven sheath and the Amplatz-like sheath tightly fitted and fixed in position relative to the tapered fascial dilator (reprinted from Goharderakhshan *et al.* [12], with permission of Elsevier).

balloon dilator is removed and the super-stiff wire secured to the drapes. At this point nephroscopic instrumentation can be introduced and stone removal undertaken.

Radially expanding single-step dilator system

A relatively new technique of tract dilation involves the use of a radially expanding single-step nephrostomy dilator (RESN) [12]. This device is made of four components: an 8F woven sleeve with an inner stylet, a 30F tapered fascial dilator, and a working sheath (Figure 20.6). The 8F woven sleeve with a rigid stylet is introduced over the guidewire under fluoroscopic guidance. The stylet is removed following the insertion, leaving the woven sleeve in the collecting system. The tapered fascial dilator with a back-loaded working sheath is inserted through the sleeve in order to dilate the tract. The sleeve must be locked in place with the nondominant hand during the dilation, in order to counterbalance the forward force of the dilator. Following the insertion of the dilator, the woven sleeve undergoes radial expansion, accommodating the insertion of the working sheath. The working sheath and the fascial dilator have to be secured in position, relative to each other, in order to eliminate inadvertent advancement of the sheath over the tip of the dilator.

The main advantage of the RESN system, like that of the balloon dilator, is in the use of lateral forces which minimize tissue trauma. In addition, the RESN system concentrates the radial forces at the tip of the dilator, thereby offering an advantage during the dilation of a heavily scarred retroperitoneum.

The main disadvantage of this system is the use of significant manual force and manual counterbalancing during the dilation, which have a potential for inducing significant renal trauma. The use of this system was initially described in a small series [12]. Its comparative efficacy and safety relative to the balloon dilator remains to be determined.

Special considerations

Obesity

A number of studies have demonstrated that percutaneous nephrolithotripsy (PCNL) can be performed effectively and safely in obese patients [13–15]. Accomplishing tract dilation, however, can be challenging due to the long tract length required, risking guidewire buckling or kinking, and an inability to reach the collecting system with the dilation instrument. This latter problem may occur with the balloon dilators. The balloon component of most dilating devices on the market is 15 cm long. In the morbidly obese patient, the balloon may be buried beneath the skin in order to reach the collecting system, making it difficult to advance the working sheath. The use of Amplatz dilators may be chosen in this scenario. With a length of 30 cm, each Amplatz dilator should be able to reach the collecting system regardless of patient size. An extra long working sheath may be required however, and should be kept on hand for such contingencies. Should the working sheath need to be buried beneath the skin, we choose to place a large silk suture through the sheath so that the sheath can easily be retrieved at the completion of the case.

Alternatively, the standard Amplatz dilator set can be augmented with the addition of a modified 10 mL syringe barrel. This modification prevents migration of the working sheath below the skin and effectively extends the length of the working sheath [16].

Pediatric patients

Continuous miniaturization of endoscopic equipment and refinement in the surgical technique has allowed percutaneous stone surgery in children. Several studies have reported on the safety and efficacy of PCNL in the pediatric population [17–21]. Tract dilation in children can be carried out with serial dilation or balloon dilation. Use of a 24F balloon dilator minimizes potential parenchymal trauma and bleeding. The technique is identical to that previously described in the adult population. Alternatively, the mini-perc technique can be used. The mini-perc access system uses an 11F × 10 cm peel-away vascular access sheath with an exposed trocar length of 1 cm. The sheath is inserted into the collecting system over an access wire and does not need sequential or balloon tract dilation. The mini-perc technique reduces the size of the percutaneous tract significantly and yet can still be effective for clearing stones [22]. It is also associated with decreased blood loss, increased maneuverability, and shorter hospital stay [23], but requires mandatory use of pediatric instruments and a greater degree of stone fragmentation prior to extraction.

Retroperitoneal scarring

Retroperitoneal fibrosis resulting from previous surgery or retroperitoneal inflammation can present a challenge during nephrostomy tract dilation. Balloon dilators used in this situation have been associated with failure rates of 17–50% [24, 25]. Balloon failure cases can be salvaged in most situations with the use of Amplatz or metal dilators.

Alternatively, when dense perinephric scarring is encountered, the use of a facial incising needle can also be used to aid tract dilation. The needle (Figure 20.7) is advanced coaxially over a previously inserted guidewire to facilitate subsequent tract dilation. The needle is rotated as it is advanced, breaking through dense fibrosis. Care must be taken not to inadvertently lacerate the subcostal or intercostal neurovascular bundle on the inferior rib margin [26]. Among thin patients, care must be taken not to advance the needle too deeply, so as to avoid reaching and lacerating the renal parenchyma.

A recent report has described the use of a cutting balloon for cases of heavy retroperitoneal scarring [27]. Although described as safe and successful in this case report, its safety in a wider context remains to be determined.

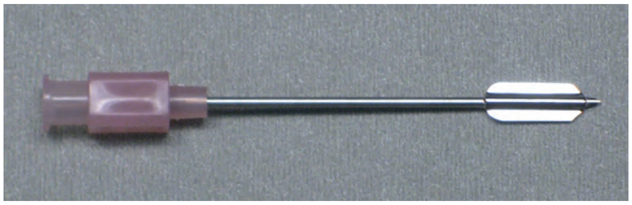

Figure 20.7 Fascial incising needle.

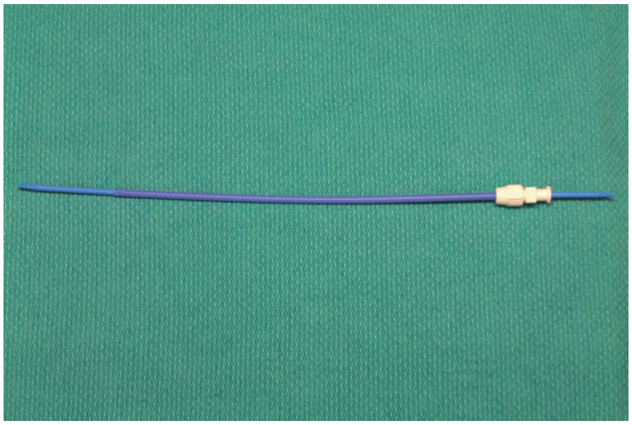

Figure 20.8 8–10F coaxial dilator.

Impacted stone in entry calyx

Renal stones tightly impacted within the intended entry calyx present a challenge for percutaneous surgery. The access can be aided by injection of contrast, relying on the generated pressure to create space around the stone [26], the use of hydrophilic wire(s) or angled-tip catheters, such as a Kumpe catheter to navigate around the stone. The main challenge in dilating the tract is to ensure the dilator can obtain enough purchase within the calyx to allow insertion of the working sheath. In this scenario, initial dilation with an 8–10F coaxial catheter (Figure 20.8) may be attempted. This maneuver will often create enough space to permit a successful reinsertion of the balloon catheter.

Potential complications

Hemorrhage

Acute hemorrhage can originate from four sources: intercostal vessels, renal parenchymal vasculature, or branches of the renal vein or renal artery adjacent to the pelvicalyceal system. The reported incidence of serious arterial injuries ranges from 0.9% to 3% after percutaneous procedures (Table 20.1) [6, 7, 9, 11, 25, 28–31]. The most clinically significant bleeding related to percutaneous tract dilation is due to over-advancement of the dilating instrument, resulting in splitting of the infundibulum. This occurrence can be avoided by

Table 20.1 Reported blood transfusion rates according to dilation technique.

Study	Transfusion rate (%)	Dilation technique
Wezel *et al*. 2009 [7]	2	Metal telescopic
Shen *et al*. 2007 [6]	2.5	Metal telescopic
Basiri *et al*. 2003 [29]	5.1	Metal telescopic
Amjadi *et al*. 2008 [30]	5.9	Metal telescopic
Gonen *et al*. 2008 [11]	21.3	Amplatz
Sofikerim *et al*. 2007 [31]	8.1	Amplatz
Turna *et al*. 2007 [32]	23.8	Amplatz
Safak *et al*. 2003 [9]	16.6	Amplatz
Tomaszewski *et al*. 2010 [35]	1.3	Balloon
Wezel *et al*. 2009 [7]	8	Balloon
Kurtulus *et al*. 2008 [25]	15.5	Balloon
Tefekli *et al*. 2008 [33]	11	Balloon
Gonen *et al*. 2008 [11]	18.6	Balloon
Duvdevani *et al*. 2007 [34]	0.8	Balloon
Joel *et al*. 2005 [28]	0	Balloon

understanding the anatomy of the entry calyx and infundibulum with retrograde contrast injection. Regardless of the dilating system used, the intention should then be to place the widest part of the dilator into the entry calyx, but not into the infundibulum.

Renal pelvis perforation

The most common cause of renal pelvis perforation is the aggressive use of serial dilators. The perforation is usually medial, following an over-advancement of the dilator. Renal pelvis perforation can also occur due to initial transgression of the puncture needle and inappropriate guidewire positioning. Acute angulation, often associated with lower renal pole entry, and guidewire kinking can also contribute to renal pelvis perforation. Initial advancement of the guidewire down the ureter and into the bladder facilitates dilation and greatly reduces the risk of this complication.

The perforation is usually recognized intraoperatively by contrast extravasation on fluoroscopy. Once recognized, it requires termination of the procedure and placement of a ureteral stent and a nephrostomy tube.

Conclusions

Acute dilation of the percutaneous nephrostomy tract is a safe and efficient technique that permits percutaneous renal surgery. A variety of dilating techniques and instruments can be used, each with specific advantages and risks. The dilation should always be carried out over a guidewire and under radiologic imaging. The choice of equipment will depend on patient profile, surgeon preference and expertise, local instrument availability, and costs.

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PART 5 Stone Removal

CHAPTER 21

Rigid and Flexible Nephroscopy

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Introduction

The first reported nephroscopy was performed in 1941 when a rigid cystoscope was placed into the kidney through a drain tract to remove stones after open kidney surgery [1]. Subsequent to this, the first percutaneous renal access was obtained in 1955 for hydronephrosis. The percutaneous route for accessing the kidney has grown in popularity, starting with the increasing use of percutaneous nephrolithotomy (PCNL) in the 1980s [2]. PCNL is now the gold standard for the removal of staghorn renal calculi due to its minimally invasive nature and high stone-free rates [3]. Rigid nephroscopes are most commonly used to clear stones from the collecting system during PCNL; however, there are times when, due to anatomic constraints, this instrument cannot perform all of the functions needed to render a patient stone free due. Also, with advances in instrumentation, use of percutaneous access has expanded to treating renal diseases such as symptomatic renal cysts, stenotic infundibula, excluded calyces, and upper tract transitional cell carcinoma.

This chapter will discuss recent advances in rigid nephroscopy, flexible nephroscopy through percutaneous access, and instruments and techniques that can maximize efficiency and minimize morbidity during various percutaneous renal procedures.

Indications for nephroscopy

Diagnostic indications

With advances in imaging technology boasting diagnostic accuracy of 76–98% for upper tract urothelial carcinoma, and better flexible ureteroscopic equipment, such as digital imaging scopes and ureteral access sheaths, nephroscopy as a purely diagnostic procedure is not routinely performed [4–6]. Occasionally, percutaneous access is the only option for access to the pelvicalyceal system, e.g. extremely difficult retrograde access after cystectomy and urinary diversion.

Therapeutic indications

With the combination of rigid and flexible nephroscopy techniques, percutaneous nephroscopy can be used to treat the following:

- Stone disease: treatment of complex calculi/staghorn calculi;
- Upper tract transitional cell carcinoma (TCC): ablation of tumors with lasers or resection with a cautery system;
- Ureteropelvic junction (UPJ) obstruction: antegrade endopyelotomy and/or endopyeloplasty with a balloon cutting device, holmium:YAG laser incision, hook knife, Sachse urethrotome, or endoscopic shears [7];
- Obstructed calyces, infundibular stenosis, and calyceal diverticula: access obtained in a “direct” manner in which the percutaneous access is directed at the obstructed area or an “indirect” approach where the obstructed area is accessed via another puncture site.

Indications for flexible nephroscopy

The chief indication for flexible nephroscopy is access to calyces with stones or tumors that cannot be reached

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Smith’s Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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with the rigid nephroscope. Williams *et al*. showed that a combination of flexible and rigid nephroscopy can be successfully used to render patients stone free, even in the face of complex stone disease [8]. Such studies show that urologists must now strive for stone-free status with a single procedure [9]. Although some studies have shown greater cost with increasing stone burden, it is unlikely that insurance companies or patients will permit the cost and morbidity of repeat PCNL procedures in the future as more urologists will have the ability to render patients stone free with one procedure [10]. Even after discharge, the cost of time away from work and to the healthcare system from secondary procedures precludes multiple sessions of extracorporeal shock-wave lithotripsy (ESWL) or repeat PCNL. In addition, the 90-day global period after PCNL surgery in the USA makes secondary procedures unappealing to urologists. However, most urologists performing percutaneous procedures commonly encounter situations where a procedure cannot be completed through a single percutaneous access. The options for dealing with these situations include obtaining another access that is more amenable to reaching the stone, leaving the stone and performing ESWL or ureteroscopy, or performing flexible nephroscopy. Flexible nephroscopy has been growing in popularity recently as surgeons have shown its use can avoid the need for an additional access [8, 11].

Flexible nephroscopy can also be used through a percutaneous access to treat obstructed calyces or a calyceal diverticulum when a rigid nephroscope cannot reach the infundibulum due to its acute angle or tightness (Figure 21.1) [12]. This indirect approach to an obstructed calyx or calyceal diverticulum is becoming more commonly utilized as opposed to a direct approach, wherein the obstructed calyx itself is percutaneously punctured, a tract established, and the stenosis treated directly. The advantage of the indirect approach is that it obviates the need for a separate nephrostomy tract with its attendant morbidity.

Occasionally, a conventional flexible cystoscope can be too large or too cumbersome to be maneuvered into a calyx. In such instances, use of a flexible ureteroscope to access difficult-to-reach calyces increases the chances of rendering a patient stone free. These are generally 7 or 8F and tend to have better deflection than the flexible cystoscope. Problems are encountered with fiberoptic flexible ureteroscopes because of their length and they are not ergonomically suited for use in the kidney; relatively flimsy nature and thus they are not torque stable; and slender profile and tight distal radius of deflection, making them difficult to maneuver in hydronephrotic collecting systems. Use of nephroscopy with a ureteroscope should be considered for stone fragments that may have migrated down the ureter during stone fragmentation in the renal pelvis.

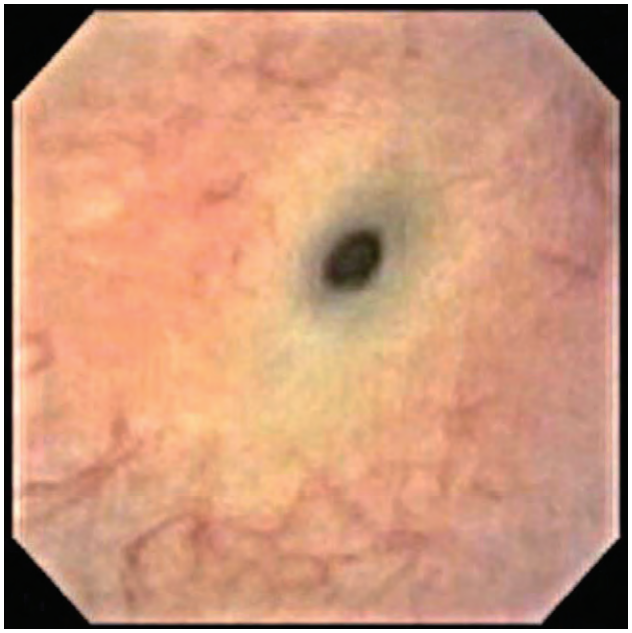

Figure 21.1 Stenotic infundibulum.

The need for flexible nephroscopy during PCNL depends largely on the location of the stone and of the access. Most urologists prefer to obtain access below the 12th rib in order to reduce the risk of pleural injury. In those cases, the rigid nephroscope is usually introduced into the lower pole. The renal pelvis can usually be reached with this access, but reaching upper and mid pole calyces without placing substantial torque on the renal parenchyma is difficult, especially in obese patients or in patients with low-lying kidneys due to hindrance from the iliac crest. It can also be challenging to reach other lower pole calyces from this position and almost impossible to evaluate the proximal ureter with a rigid nephroscope (Figure 21.2). Alternatively, if access is into the upper pole, it can also be difficult to reach the lower pole calyces, especially in patients with narrow intercostal spaces or nonmobile (fixed) kidneys.

Preoperative routine

Preoperative planning should include a careful review of imaging, whether an intravenous pyelogram or a computed tomography (CT) scan. Generally, a CT scan will enable the surgeon to better assess the anatomy, stone burden and location, and calyceal structure of the kidney to be accessed. Particular attention should be given to the location of pleura in relation to the kidney, as well as any bowel and organs that could be in the access path; especially in cases of anomalous kidneys (malrotated kidney, horseshoe kidney, ptotic kidneys, pelvic kidneys, cross fused ectopia, etc.) that may force the surgeon to obtain unusual access [13–15]. In

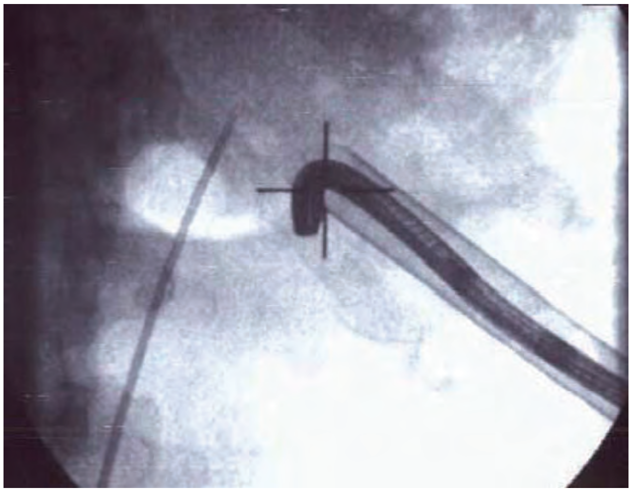

Figure 21.2 Reaching the lower pole calyx with a flexible scope.

Table 21.1 Concordance of preoperative voided urine cultures with intraoperative renal pelvis and stone.

Type of specimen	Positive culture	Matches preoperative voided urine Culture	Matches intraoperative renal pelvis culture
Preoperative voided urine culture (n = 57)	18 (31%)	N/A	–
Intraoperative renal pelvis culture (n = 57)	9 (16%)	5/9 (55%)	N/A
Intraoperative stone culture (n = 57)	10 (17%)	4/10 (40%)	3/10 (30%)

planning the treatment of UPJ obstruction with endopyelotomy, a CT scan of the abdomen in an angiographic phase should be obtained to delineate the presence of a crossing vessel.

Preoperative urine culture should be obtained and be negative whenever possible. However, in cases where a patient may have an infected renal calculi, it may be difficult to achieve complete sterility even with culture-specific preoperative antibiotics. In fact, data from our institution suggest that there is a fair degree of discrepancy between preoperative voided urine culture, intraoperative renal pelvis culture, and intraoperative stone culture [16]. Table 21.1 shows the concordance of the urine cultures obtained in patients who underwent PCNL at our institution.

Other laboratory work-up should include tests for renal function and electrolyte abnormalities. Patients should be instructed to stop all Aspirin products at least 10 days prior to surgery. Patients who are constantly anticoagulated on warfarin need to discontinue this to allow the PT/INR to normalize, and short-acting heparin products given instead. Typing of blood should always be obtained prior to surgery, as well as blood transfusion consent.

Perioperative routine

Generally, percutaneous renal procedures are performed with general anesthesia with the patient in the prone position. Recently, studies have shown that PCNL can be safely performed under regional anesthesia and in other positions such as a lateral decubitus position [17, 18] (see Chapters 8, 10, and 11). Surgeons have performed successful percutaneous procedures using the following patient positions:

- Prone;
- Prone on spreader bars: allows access to genitalia to perform simultaneous retrograde nephroscopy [19];
- Prone–flexed: allows better access to upper pole [20];
- Supine position: allows normal anesthesia access to respiratory tract; allows easy access to lower urinary tract;
- Valdivia–Galdakao position: intermediate dorsal decubitus position with extension of ipsilateral lower limb and flexion of contralateral lower limb [21, 22].

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Figure 21.3 Smith digital nephroscope (GYRUS ACMI, Southborough, MA, USA) (reproduced courtesy of Gyrus ACMI).

Advances in scope technology

Although flexible scopes afford more maneuverability, there is little disagreement that the quality of the image is better with a rigid nephroscope; especially with the advent of the new rigid Smith digital nephroscope (Figure 21.3) (Gyrus; ACMI, Southborough, MA, USA) [23]. This scope allows access to calyces that are not normally accessible with rigid nephroscopes because it boasts a large working channel with better irrigant flow

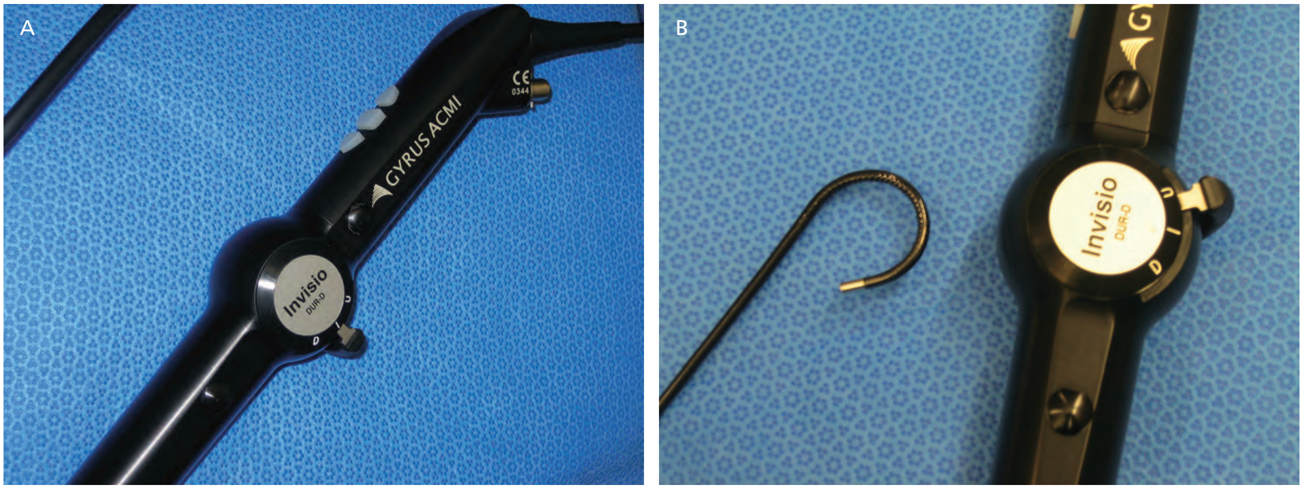

Figure 21.4 Invisio DUR-D digital flexible ureteroscope (Gyrus ACMI, Southborough, MA, USA).

(15F), is longer (18 cm vs 15 cm), lighter (470 g compared to 939 g), and more maneuverable without a bulky camera head. Its digital "chip on a stick" technology allows better contrast, color, and resolution than other scopes, making it easier to identify infundibulae even in the face of severe edema, bleeding, or stenosis. In addition, the dual distal light emitting diode (LED) light sources eliminate the need for a separate light cord and improve image brightness.

There are also new and improved digital flexible cystoscopes that show improved color, contrast, and resolution compared to traditional fiberoptic cystoscopes. Studies comparing digital to fiberoptic cystoscopes have shown that the digital scopes have improved resolution, contrast discrimination, and red color differentiation and are as durable as the older scopes [24, 25]. In addition to optics, the digital cystoscopes also have better deflection in both directions and are more torque stable compared to their fiberoptic counterparts, making navigation easier, especially in very tight or very hydronephrotic collecting systems.

A new advance in the use of flexible ureteroscopes for access to difficult-to-reach calyces and the ureter is the digital distal sensor ureteroscope (DUR-D, ACMI) (Figure 21.4). This scope provides excellent resolution and superior optics compared to traditional fiberoptic ureteroscope. It also deflects further away from the distal tip (270° degrees in either direction), giving it better maneuverability (Figure 21.5). At 8.5F, it will fit into most calyces.

A very useful technique that has been recently described and adopted is placing the flexible ureteroscope through the working channel of the rigid nephroscope so that it can be better directed toward an intended target (Figure 21.6). This is particularly useful with an additional video tower so that images from both the nephroscope and the ureteroscope can be simultaneously viewed. In particular, placing the DUR-D digital

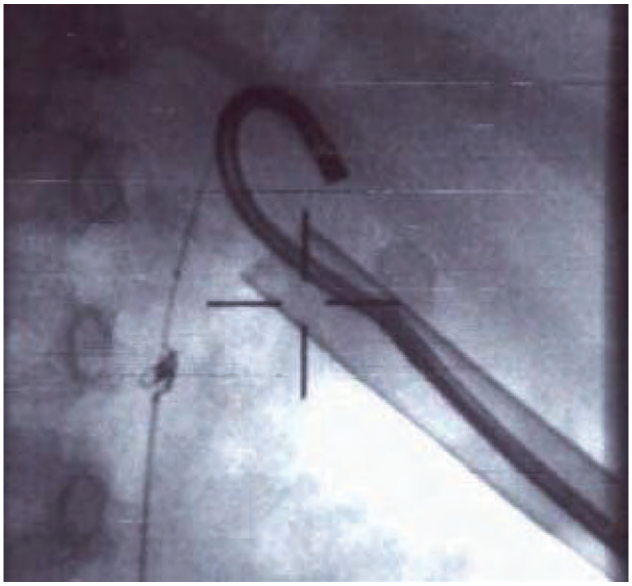

Figure 21.5 Excellent deflection of the DUR-D digital ureteroscope.

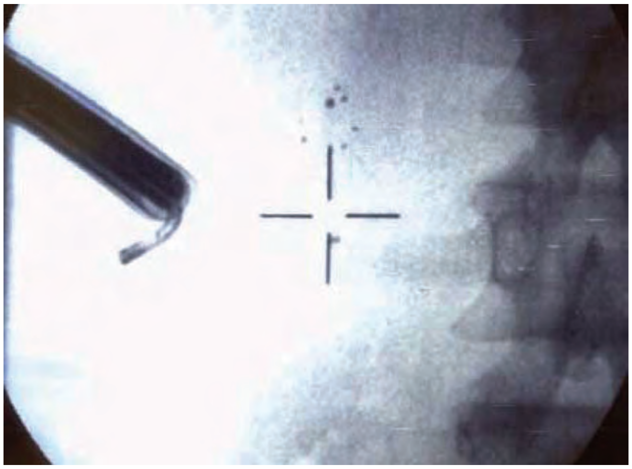

Figure 21.6 Flexible ureteroscope is inserted through the rigid nephroscope.

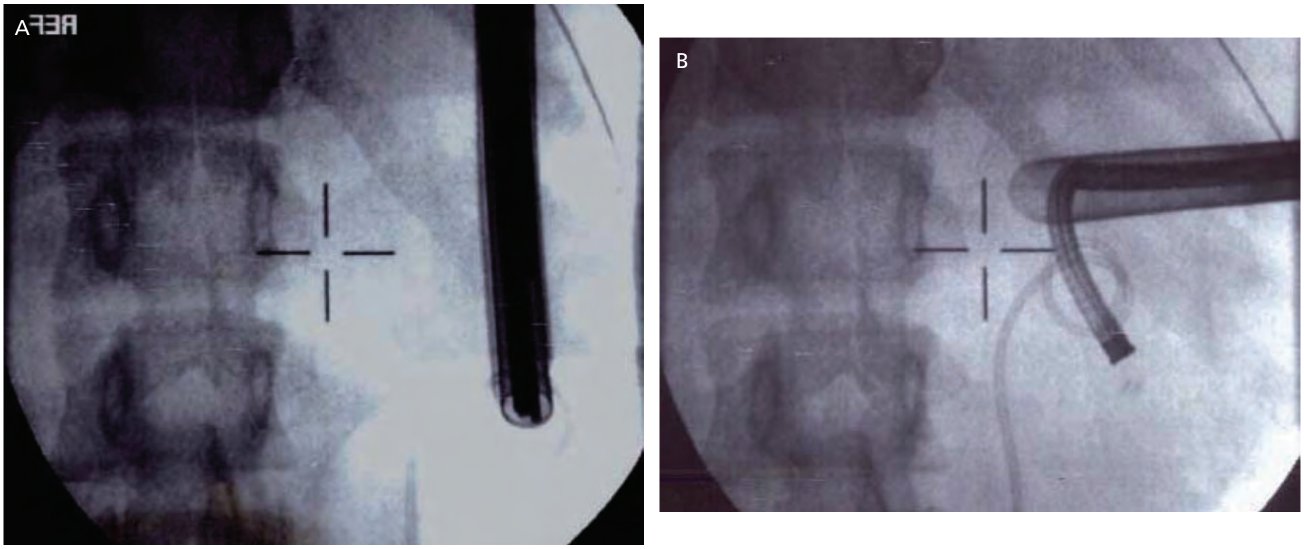

Figure 21.7 (A) Reaching a anterior lower pole calyx with a rigid nephroscope. (B) Reaching a posterior lower pole calyx with a flexible nephroscope.

ureteroscope through the large working channel of the new Invisio Smith digital nephroscope provides a fantastic image [23].

Importance of access site

As mentioned earlier, initial percutaneous access to the kidney influences which calyces can be reached. If a patient has a single stone in a mid pole calyx, it makes most sense to access that calyx directly. If there are multiple stones or staghorn calculi, access is often obtained in the upper or lower pole, making mid pole access difficult to reach with a rigid scope. Also, since a rigid scope entering posteriorly faces the anterior calyces, it is more difficult to go from a posterior calyx to another posterior calyx. Some general guidelines for various access sites are given below.

Posterior upper pole access

If posterior upper pole access is obtained, generally the other more anteriorly located upper pole calyces can be reached with the rigid nephroscope even if there is a moderate degree of hydronephrosis. If there is no significant hydronephrosis, or if the access site is close to the infundibulum instead of the peripheral end of the calyx, then it most likely will not be possible to visualize or enter the other upper pole calyces and flexible nephroscopy is necessary. From the upper pole, usually the anterior lower pole calyces can be entered with the rigid nephroscope, but the posterior ones cannot (Figure 21.7). Unless there is significant hydronephrosis, the mid pole calyces cannot be entered at all and flexible nephroscopy will be necessary.

Mid pole access

As previously mentioned, if posterior mid pole access is obtained, usually the rigid scope cannot access anything other than the renal pelvis and ureter. This access should only be chosen if stones are located in a solitary mid pole calyx and/or the renal pelvis or proximal ureter.

Posterior lower pole access

With a posterior lower pole approach, often the other more anteriorly located lower pole calyces can be entered if the access site chosen is more *medial* than usual. To achieve this, instead of rotating the C-arm through the usual 30º toward the surgeon, it is rotated only 20º. This slightly more medial approach, in our experience, does not risk vascular injury and yet provides excellent ability to reach all lower pole calyces. It is particularly useful for partial staghorn calculi that have no upper or mid pole components. From the lower pole, unless there is severe hydronephrosis, the upper and mid pole calyces cannot be reached at all and flexible nephroscopy is necessary to clear them of residual stones (Figure 21.8).

Likewise, the ureter cannot be accessed with rigid scopes or instruments, and flexible scopes are needed. Use of the Accordion™ device (Percsys, Palo Alto, CA, USA), a 15-mm coaxial film-based occlusion device, permits lower pole access for complex stones without fear of stones migrating down the ureter that will then require flexible ureteroscopy at the end of the procedure (Figure 21.9) [26]. Use of this device can ultimately help save time and cost of percutaneous stone procedures.

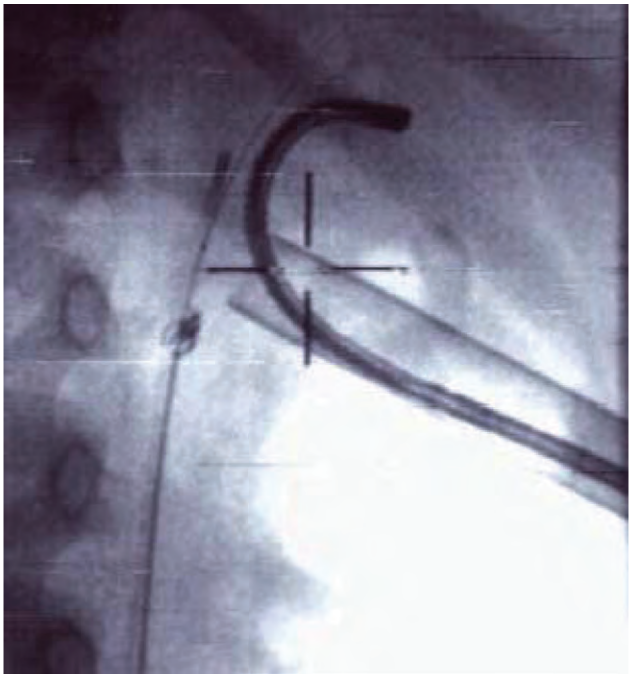

Figure 21.8 Reaching upper pole calyces with lower pole access.

Intercostal access

The degree of maneuverability also depends on whether triangulation was used to obtain upper pole access or if an intercostal approach was chosen. Intercostal access will usually allow more maneuverability with less torque on the renal parenchyma, provided that the intercostal space is wide enough. On occasion the space between ribs is very narrow and the sheath is sandwiched so tightly that maneuverability is significantly hampered.

Tips and tricks

Flexible nephroscopy

This section will discuss different techniques that assist with use of the flexible nephroscope and obtaining safe percutaneous access. One tip is to minimize the use of contrast. If contrast extravasates outside the collecting system, fluoroscopic visualization of residual stones is very difficult. In our experience, contrast is used only at the very beginning of the procedure to outline calyceal anatomy and to help guide access, then again at the very end after the nephrostomy tube has been placed.

Often, visualization is adequate with a rigid scope because of high volume irrigation, but once the flexible scope is employed visualization dramatically deteriorates if there is any bleeding at all. This is partly due to the optics, but even more to the reduced irrigation with

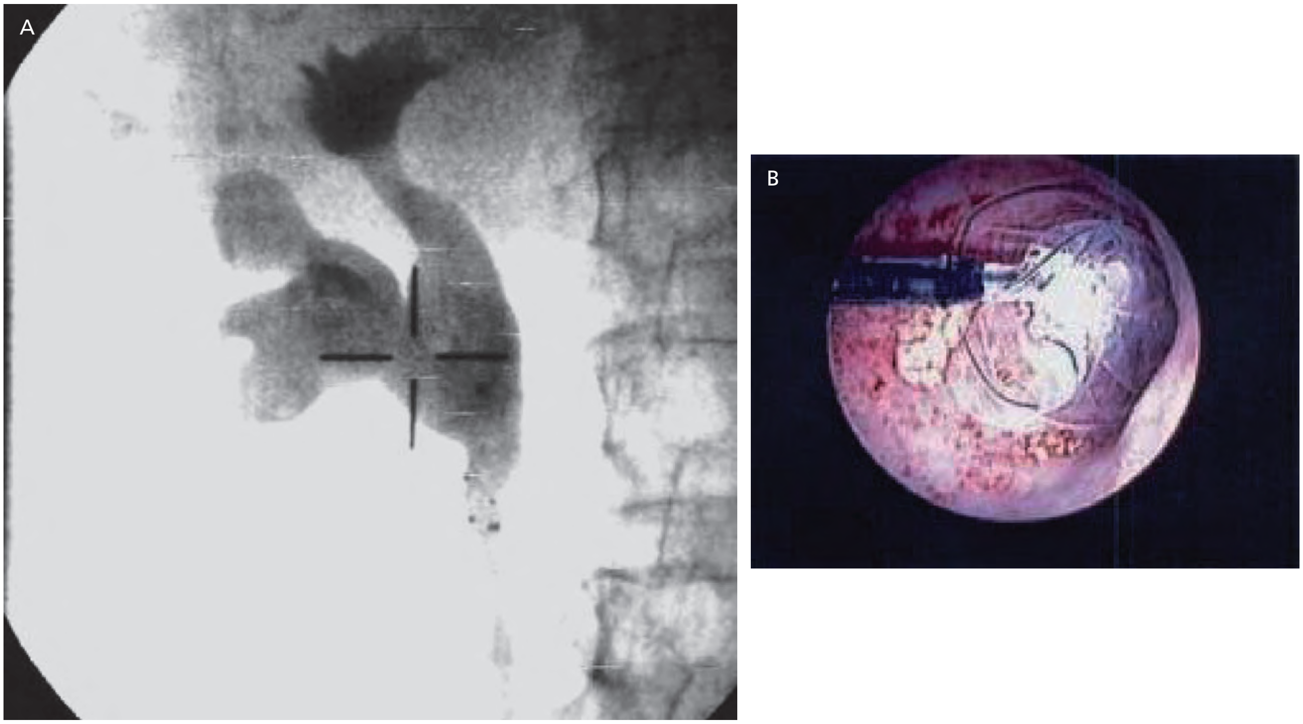

Figure 21.9 Fluoroscopic image of the Accordion™ device (Percsys, Palo Alto, CA, USA) deployed at the ureteropelvic junction. (B) Accordion device preventing antegrade stone migration.

a flexible scope and the inadequate distention of the collecting system. Use of pressure bag irrigation can significantly enhance visualization by clearing the field of blood and by distending the collecting system.

One important technique is the use of fluoroscopy to help guide placement of the flexible nephroscope. If direct visualization is not sufficient to visualize an intended calyx (either because of angulation, a severely hydronephrotic collecting system, or bleeding), brief continuous fluoroscopy can be used to gently maneuver the scope to a stone in a peripheral calyx. This is generally a very safe maneuver because the blunt end of a flexible nephroscope is wide and atraumatic. Also, since the scope is flexible, perforation is unlikely.

If the opening to a calyx can be visualized with a rigid scope, but it is difficult to find with a flexible scope because of bleeding or incomplete distention of the collecting system, a guidewire can be placed into the intended calyx via the rigid scope. The best wire to use for this purpose is a short, heavy-duty J wire (Cook Urological, Spencer, IN, USA). The short J wire with the "J" hooked distal tip is atraumatic and therefore is less likely to perforate the calyx or to be dislodged while transitioning from the rigid scope to a flexible one. The flexible scope is not placed over the wire, which almost always results in the wire becoming dislodged from the calyx; instead, the flexible scope is placed alongside the wire and the wire is followed to the calyx of interest. In this manner, the working port of the flexible scope is free for the placement of instruments. In addition, the calyx can be entered again and again without the wire having to be replaced.

Another tip mentioned earlier is placing a flexible ureteroscope through the rigid nephroscope. This is particularly useful when the infundibulum to the targeted calyx is narrow and will not accommodate a flexible nephroscope. The smaller girth of the flexible ureteroscope means it can enter almost all calyces, but maneuvering these scopes in the collecting system can be challenging because of poor irrigation through their small working channels, their excessive length, their tight radius of curvature, and their lack of torque stability. By visualizing the infundibulum with a rigid scope, the flexible ureteroscope can be guided into the calyx by a second surgeon through the working port of the rigid scope, which the first surgeon holds steady. Once the calyx is entered, the camera can be switched to the flexible scope. Alternatively, two video towers can be employed so that simultaneous views from the rigid and flexible scopes can be obtained.

Stone fragmentation, retrieval, and patient positioning

Once the affected calyx is reached with the flexible nephroscope or ureteroscope, the size of the stone(s) to be removed must be gauged relative to the width of the infundibulum. If it is likely that the stones can be pulled through the infundibulum intact, a basket or grasper can be used. The N-gage basket (Cook Urological) is particularly useful for efficiently grasping a stone (Figure 21.10). The advantage of this device is that it has an open end and can "cup" a stone that is attached to a papilla or is impacted against the wall. In addition, if the stone is too large to pull through the infundibulum, it can be easily released.

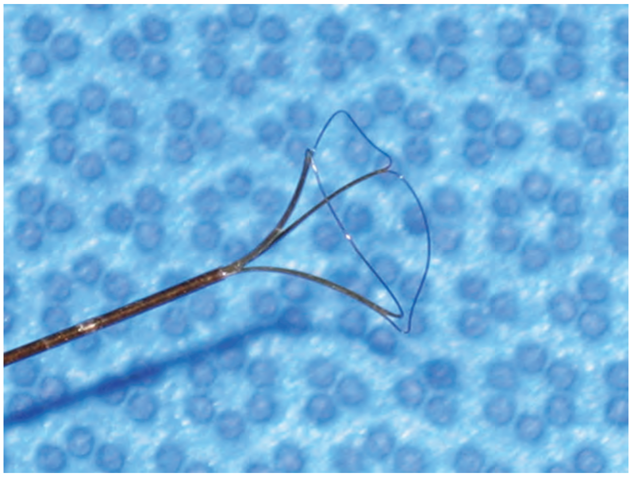

Figure 21.10 N-gage basket (Cook Urological, Spencer, IN, USA).

Baskets are useful for free-floating stones. A basket must be chosen that is sturdy enough to remove the fragments but small enough to allow the scope to deflect. For flexible nephroscopes with their large working channels, 2.4 or 3F nitinol baskets should be used because they are sturdier than smaller profile baskets and can grab larger fragments. For flexible ureteroscopes, 8F or smaller baskets are preferred because they permit better irrigation.

If the stones to be removed are too large, the holmium:YAG laser can generally be used for lithotripsy. It is important to balance the size of the fiber with the deflection of the scope; a larger fiber will make it more difficult to deflect but will disintegrate the stone faster. Most endourologists generally use a 360-μm fiber through the flexible nephroscope, but a 200-μm fiber through a flexible ureteroscope as it easily fits through all flexible ureteroscopes without significantly affecting deflection or irrigation. The settings to be used depend on the effect desired and the nature of the stone. If the intention is to create miniscule particles that will be left behind for spontaneous passage or flushed out of the calyx and then suctioned (uric acid, phosphate, and struvite compositions are most amenable to this), then low power (i.e. 0.5 J) at a faster frequency (i.e. 10–15 Hz) should be used, and the periphery of the stone should

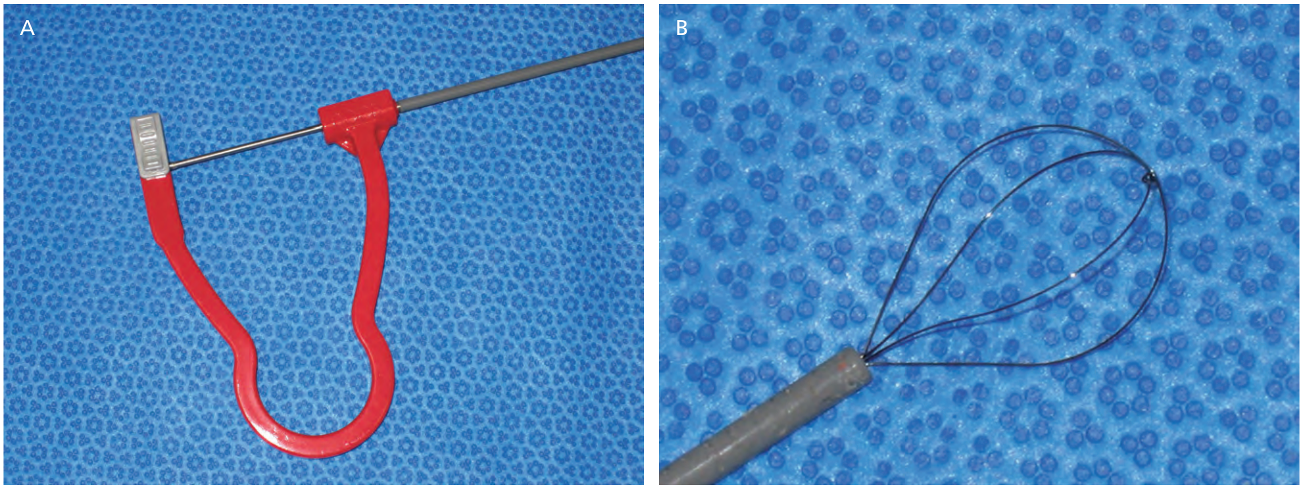

Figure 21.11 Perc-N-Circle device (Cook Urological, Spencer IN, USA).

be ablated gradually until the center is reached. The remaining central piece can be retrieved with a grasper or basket. If the stone is very durile (e.g. a calcium oxalate monohydrate or cystine stone), then it should be carved into a few large pieces using high power (1.0 J) and lower frequency (5–8 Hz). The resultant pieces should be removed in piecemeal fashion.

Tiny fragments that are too small to basket are often broken off by the laser. One technique is to irrigate with a 10-mL syringe through the working channel of the flexible scope to flush out these fragments. If they are small enough, they can even be aspirated with the syringe. The most effective technique also includes changing the position of the patient to maximize the drainage of these fragments. For instance, if the patient is in the prone position and the fragments being flushed are in an anterior calyx, the patient can be rotated to the opposite side so the fragments fall into the renal pelvis. One can also use Trendelenberg and reverse Trendelenberg as necessary to allow stones to enter the renal pelvis. Fragment migration into the ureter is mitigated by using the Accordion device, as mentioned above. From the renal pelvis, the fragments can be easily retrieved by the rigid nephroscope using atraumatic peanut forceps with minimal to no irrigation, keeping the patient tilted away from the surgeon to keep the fragments from falling back into the anterior and lateral calyces.

On occasion the Perc-N-Circle device (Cook Urological) can be invaluable for retrieving stones from otherwise inaccessible calyces via the rigid scope (Figure 21.11). This unique device is a 5-mm coaxial semi-rigid instrument with a tipless, large nitinol basket on the distal aspect. Deployment of the basket into a calyx is usually possible as long as the infundibular neck of a calyx can be directly visualized, even if the neck is too small or too peripheral to allow direct access with the scope. Using a combination of direct vision or fluoroscopy, stones can be readily insinuated into the basket and retrieved by pulling them out through the infundibulum. If the neck is too tight to allow stone removal, it is a relatively simple task to open the basket and disengage the stone.

Obtaining safe percutaneous access and preventing ureteral stone migration

During PCNL the coaxial Accordion™ device (Figure 21.12) can serve several purposes. It is usually placed in the collecting system over a guidewire at the beginning of the case and deployed at the UPJ. Since the lumen of the device accommodates a 0.38-inch guidewire, it is ideal for performing urine sample collection as well as retrograde pyelography. Once it is deployed at the UPJ, it is very effective in preventing stone migration down the ureter, obviating the need for ureteroscopy at the end of PCNL [27].

Intercostal renal access during PCNL and other percutaneous renal procedures is associated with an increased incidence of pneumothorax, hydrothorax, or hemothorax postoperatively. The Accordion device can be used to prevent upward migration of the kidney in situations when intercostal access initially appears unavoidable, allowing establishment of a more favorable subcostal renal access (Figure 21.13). Deployment of a coaxial film-based occlusion device at the UPJ can be used to gently hold the kidney in its lower position during ventilation, and in this position percutaneous needle placement can be obtained without the need to go above the ribs. This method provides an effective way to obtain more favorable percutaneous access, potentially avoiding complications associated with intercostal renal access. Due to the atraumatic nature of this device, it has been confirmed endoscopically that

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Figure 21.12 Coaxial Accordion device deployed at ureteropelvic junction (reproduced with kind permission from Percsys).

there are no injuries at the UPJ when it is used to provide gentle traction [28].

Specific techniques

Infundibular stenoses

Infundibular stenoses are characterized by a narrow infundibulum leading to a dilated or nondilated calyx with or without stone(s) [29]. They can be caused by extrinsic compression by malignancy or retroperitoneal fibrosis, or intrinsic narrowing from tuberculosis, chronic stones, infection, or scarring. It is rarely caused by a crossing segmental artery, known as Fraley's syndrome [30]. This condition can cause flank pain, hematuria, and deterioration of renal function. Surgery of infundibular stenosis generally involves percutaneous access into the hydrocalyx, but occasionally an anterior calyx is accessed or it cannot be reached percutaneously. In these instances flexible nephroscopy can be helpful.

The two indications for treating an infundibular stenosis are relief of obstruction (dilated calyx) or a retained stone (calyx may be dilated or not). It should be noted that defining an infundibulum as stenotic is a relative distinction in that some infundibular stenoses may not truly be causing obstruction (no dilation of the calyx beyond) but are simply too small to accommodate a ureteroscope or nephroscope. In the latter situation, the main indication to surgically open the infundibulum would be for diagnosis (e.g. ruling out transitional cell

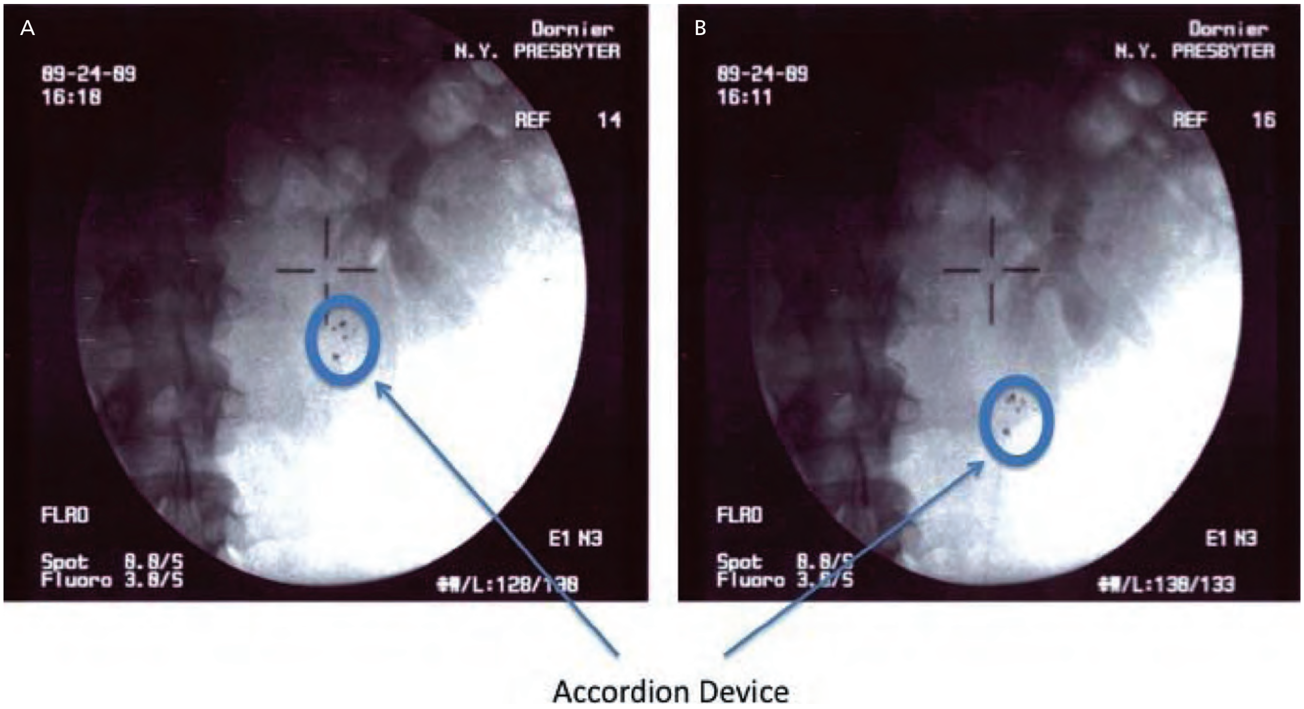

Figure 21.13 Accordion device (Percsys, Palo Alto, CA, USA) preventing upward migration of the kidney.

carcinoma in a patient with positive cytologies) or treatment of a pathology in the calyx above (e.g. stone or tumor).

Our technique first involves cannulating the infundibulum with a guidewire if it is extremely tight. A hydrophilic-coated guidewire is preferable for this since it can readily be coiled in the calyx beyond. The reason for placing this guidewire if the stenosis is very tight is that in the course of incision a false passage can inadvertently be created and the true opening obscured by a flap. If this occurs, access to the calyx is lost and complete obstruction could result. If the stenosis is approachable with a rigid scope, the peanut forceps can occasionally be used to gently dilate the infundibulum enough to permit subsequent entry with a flexible scope. Alternatively, a holmium:YAG laser or balloon (6 mm × 4 cm) can be used. If the stenosis is approachable only with a flexible scope, a holmium:YAG laser can be directed to the affected area. The infundibulum is then incised inferiorly and superiorly, as anatomic studies have shown less blood supply in these areas (Figure 21.14) [30].

A balloon can sometimes be used instead or in addition to the laser. The proximal end of a double pigtail stent can be placed in the hydrocalyx and often a stent is then placed across the newly opened area and left for 4–6 weeks. The size of the stent does not affect the eventual patency of the infundibulum [31].

If there is a stone in the hydrocalyx above a stenosis, the preferable approach is to open the infundibulum wide enough to permit intact retrieval of the stone. The reason for this is that any fragments created can become lodged in the incised tissues, potentially creating an inflammatory response that could promote restenosis. Thus, all stones from the collecting system should be cleared before treating a stenotic infundibulum.

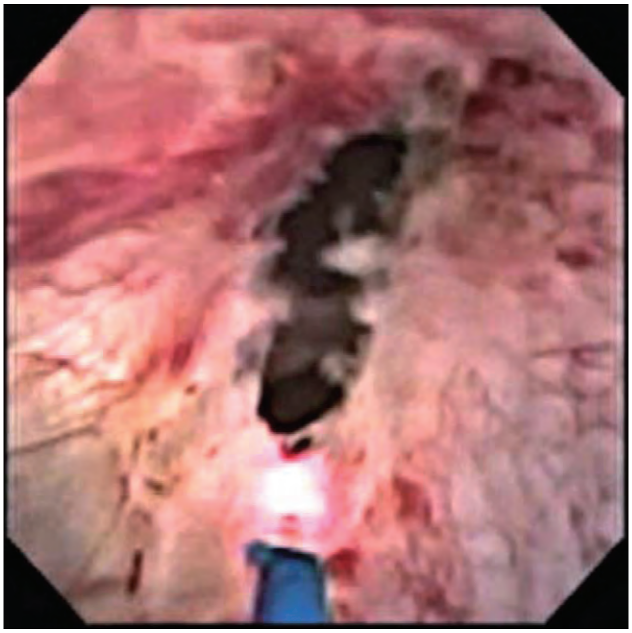

Figure 21.14 Incision of the stenotic infundibulum.

Possible complications of this approach include bleeding and eventual restenosis. As mentioned previously, the incisions should be made superiorly and inferiorly, and an effort should be made to maintain hemostasis at the time of surgery. Hemostasis can be achieved by defocusing the laser (i.e. increasing the distance from the tip of the fiber to the tissue) to create a blanching (coagulation) of the bleeding tissues. If this is not effective, then a bugbee electrode can be used with a coagulation setting of 20 W to achieve hemostasis. The downside of using a bugbee is that there is a higher likelihood of restenosis due to cicatritial contracture and ischemia. If bleeding is still present, a large caliber stent or nephrostomy tube can be placed across the infundibulum to aid in tamponading the area.

Excluded calyx

Occasionally an infundibular stenosis will be so severe that the calyx closes off completely and there is no communication between it and the renal pelvis. This condition is often diagnosed when a patient has an area of obvious hydronephrosis and no contrast flows into the expected calyces on a retrograde pyelogram [32].

There are three alternative treatments for this condition. First is retrograde ureterorenoscopy with laser incision. This is usually blind since no infundibulum can be visualized. Sometimes there is a slight dimple or area of scarring that provides a hint that an infundibulum was previously present. It is very helpful to know if the invisible hydrocalyx is anteriorly or posteriorly located in order to guide where the incision should be made. Most commonly, the affected calyx is the posterior upper pole calyx and therefore the incision should be made at the 6 o'clock position in the most superior location of the renal pelvis. This technique can lead to significant parenchymal bleeding and a bugbee electrode (a 2F electrode is preferred because it permits adequate irrigation) should be readily available.

The other two techniques involve percutaneous access. The indirect approach is particularly useful for anteriorly located excluded calyces and involves access to the opposite pole of the excluded calyx. If the excluded calyx is located in the upper pole, a lower pole posterior calyx is accessed and if it is in the lower pole the superior pole posterior calyx is accessed. After visualizing the renal pelvis, the excluded calyx is entered with either a laser or peanut forceps. This approach can be aided by placing a needle into the excluded calyx under ultrasound guidance and instilling contrast to help fluoroscopically guide the incision.

The preferred approach to an excluded calyx that is posteriorly located, however, is a direct percutaneous approach [12]. An open-ended catheter is placed into the renal pelvis close to where the original infundibulum is suspected to be. A needle is now placed percutaneously and directed toward the tip of the ureteral catheter in two planes. If the excluded calyx is in the upper pole, the needle is placed through the upper pole of the kidney into the renal pelvis. If the calyx is in the lower pole, then the needle is placed through and through the lower pole of the kidney until the renal pelvis is accessed and clear fluid obtained. A super-stiff Amplatz-J wire is coiled in the renal pelvis, and then the tract into the renal pelvis is dilated with a fascial dilator and then with a balloon-dilating catheter. Almost invariably the percutaneous tract goes through the excluded calyx and the technique is successful in creating a large neoinfundibulum. If significant bleeding is encountered, fulguration can be performed with a rollerball electrode. To keep the neoinfundibulum open, the preference is to simultaneously place two parallel ipsilateral stents (6F or 7F) that coil proximally in the excluded calyx and distally in the bladder. Alternatively, a large-bore Foley catheter can be placed through the neoinfundibulum with the balloon in the renal pelvis and a side hole created to drain the calyx. However, this is usually uncomfortable for the patient and is impractical to maintain for the 4–6 weeks that are required for healing.

Symptomatic renal cysts

Renal cysts are often discovered incidentally on routine imaging for other indications and are usually asymptomatic. Occasionally, a parapelvic cyst may become so large that it causes distortion of the collecting system and obstruction of the renal calyces [33]. These obstructing parapelvic cysts will often cause flank pain and need to be ablated using a laparoscopic technique or a percutaneous approach. During PCNL, an asymptomatic exophytic or parapelvic cyst may need to be ablated or simply drained in order for the surgeon to access the calyx with the stone.

The preferred approach to treat these parapelvic cysts depends on the aim of treatment. For instance, if a parapelvic cyst is asymptomatic but obstructs access to a calyx, it is relatively simple to drain the cyst with a needle to restore the normal renal anatomy. Once the normal renal anatomy is restored, it is possible to puncture into the intended calyx as usual. If the cyst is not aspirated first, the tract is dilated and the cyst is unintentionally entered with the nephroscope, it may be impossible to navigate into the collecting system.

To ablate the cyst directly, initially a ureteral catheter is placed for retrograde pyelography in the supine position, then the patient is turned prone as for a PCNL. The distortion of the calyces from the parapelvic cyst is confirmed with retrograde pyelography. An 18G spinal needle is placed into the cyst transparenchymally using the triangulation technique. The tract is balloon dilated to 30F, and a 30F Amplatz sheath is placed in the cyst. With a standard continuous flow 26F resectoscope with a rollerball or loop, the cyst wall is fulgurated using electrocautery. In some instances, cyst wall can be harvested for analysis. Also, portions of the cyst wall can be excised to marsupialize the cyst into the retroperitoneum or the collecting system. Patients are usually left with a drainage tube in the cyst itself, which is removed in 1–2 days [34].

Bipolar rather than monopolar electrocautery is now preferred to ablate the symptomatic parapelvic cyst and prevent recurrence. Bipolar electrocautery has been studied in the management of benign prostatic hyperplasia, and a major advantage of this technique is the ability to use isotonic saline as the irrigant solution with minimal changes in serum sodium despite long operative times [35–37]. Percutaneous ablation of parapelvic renal cysts with electrocautery has been shown to be effective with minimal morbidity [34]. Since absorption of irrigant during percutaneous procedures can be high, the use of bipolar electrocautery and isotonic saline irrigation during percutaneous ablation of symptomatic parapelvic cysts is preferable.

In our experience, percutaneous ablation of symptomatic parapelvic cysts using bipolar electrocautery is safe, and causes significantly less postoperative hyponatremia compared to a monopolar electrocautery system (Figure 21.15). It also appears to have an efficacy similar to that of the monopolar system [37].

Conclusions

Advances in flexible nephroscopy and instruments available for percutaneous renal procedures have made it possible to perform surgery more efficiently and safely. Many of the instruments and techniques discussed increase access to difficult calyces during percutaneous renal procedures and reduce the need for additional percutaneous access. Flexible nephroscopy is also helpful in cases of infundibular stenosis, excluded calyces, and symptomatic parapelvic cysts to improve drainage and reduce infection and stone formation. It is hoped that the techniques outlined in this chapter will help urologists to expand their indications for flexible nephroscopy, increase their comfort level with new scopes and accessories, and attempt the techniques before adding another access during a difficult percutaneous renal procedure.

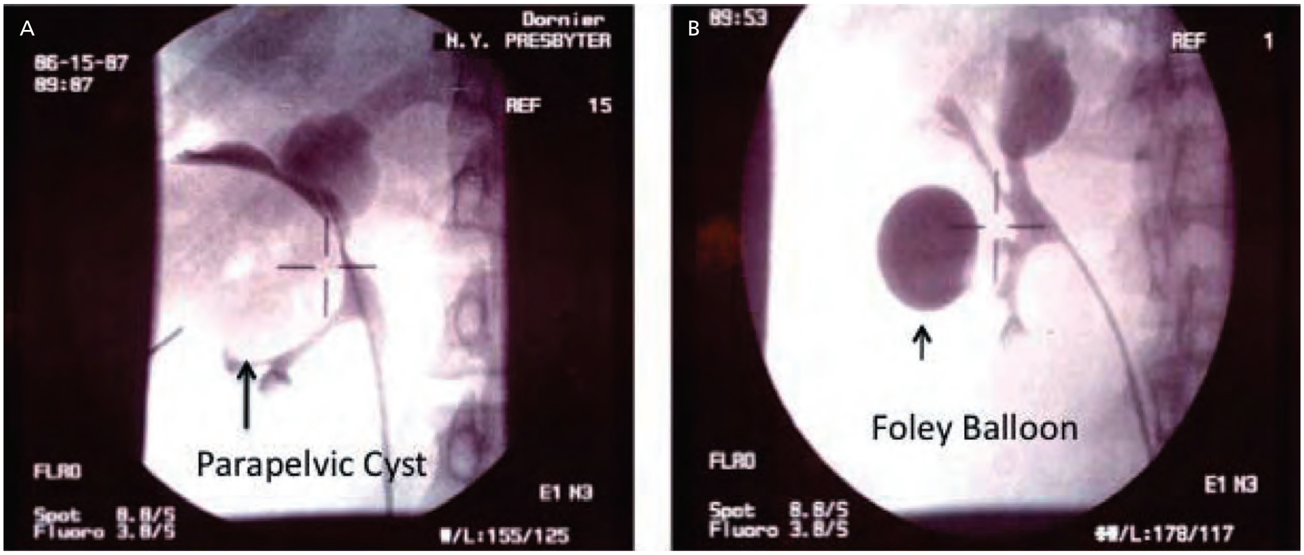

Figure 21.15 Parapelvic cyst before puncture and after ablation with a Foley balloon.

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CHAPTER 22

Percutaneous Treatment of Ureteral Stones

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Indications (Table 22.1)

Percutaneous antegrade ureteroscopy is an exceptional treatment modality for ureteral stones and is indicated when extracorporeal shock-wave lithotripsy (ESWL) or retrograde ureteroscopy (URS) are anticipated to have low success rates or increased risk of complications, or when they are not possible due to anatomic variations or abnormalities.

ESWL is a first-line treatment for ureteral stones regardless of their size and location [1]. However, success rates are highly dependent on the size and location of the stone, shock-wave technique, and patient characteristics, with best results achieved for stones of less than 10 mm in diameter located in the upper ureter [2–6].

URS is the preferred treatment for ureteral stones greater than 10 mm in diameter [1, 7–9]. It has demonstrated higher success rates than ESWL, albeit at the expense of slightly higher complication rates. While initially restricted to the distal and mid ureter, advances in instrumentation and ablation technology enable current scopes to reach and treat stones along the entire ureter, regardless of their size or composition. Stone location in the upper ureter, stone impaction, and procedure performance by a nonendourologist have been most consistently associated with decreased stone-free and increased complication rates such as ureteral injury and stricture [10].

Although the great majority of patients with ureteral stones will be treated by either URS or ESWL, specific cases may be better approached percutaneously (Figure 22.1). As a general concept, the more discouraging a setting is for retrograde URS, the more attractive it is for antegrade access, as in the cases of large stones with proximal hydroureteronephrosis (Figure 22.2), altered anatomy, concomitant ureteral and renal stones, severe stone impaction, presence of distal ureteral stricture or tortuousness (Figure 22.3), ESWL or URS failure, previous urinary diversion, or nonrefluxing ureteroneocystostomy, or any combination of the above [11–19].

A typical candidate for the antegrade approach is a patient with a large (≥15 mm diameter) and impacted upper ureteral stone with concomitant proximal hydronephrosis. A dilated upper ureter enables removal of intact stones and repetitive easy fragmentation. There is no risk of proximal fragment migration, and synchronous kidney stones can be easily cleared during the same session. Distal migration is not common, as the ureter below the stone is usually not dilated, but when it does, it can be easily managed with flexible antegrade ureteroscopy, and stone extraction through a dilated proximal ureter.

Patients with urinary diversions or nonrefluxing ureteroneocystostomy are attractive candidates for an antegrade or combined (antegrade and retrograde) approach. Difficulties in finding the ureteral orifice, accessing the ureter (especially on the left side), and negotiating through a floppy bowel, as in cases of ileal conduit and especially in neobladders, make the purely retrograde approach extremely difficult to accomplish. Percutaneous access is the preferred alternative, as some degree of hydronephrosis is usually present, and nephrostomy tubes for decompression, harbored by many patients, can be used as an access to the kidney. The procedure can be performed completely with an antegrade approach, or a percutaneously placed guidewire

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can be used to guide a flexible ureteroscope from below (combined approach). Should incision of ureteroenteric strictures or stone extraction be needed, they are best achieved from above.

Preoperative evaluation

Preoperative evaluation is directed to three main points: burden of stone disease, anatomy of the upper tract, and general patient status. In most cases, the first two aspects are assessed with noncontrast helical computed tomography (NCHCT). Stone size and location, together with additional renal stone burden, are revealed with precision. Calyceal and ureteral anatomy is also clearly evidenced. In the modern endourology era, the CT scan has completely displaced intravenous pyelography (IVP) as the preferred test for preoperative planning [20, 21]. The main advantages of CT are comprehensive three-dimensional (3D) assessment of the intrarenal collecting system anatomy and the relation of the kidney to adjacent intraperitoneal and retroperitoneal organs and vasculature.

If the patient has undergone previous URS, operative reports should be retrieved and relevant information taken into consideration. Intraoperative complications and stone impaction are of special interest. If either of these was present, the possibility of ureteral stricture (usually at the original stone location) should be highly suspected and proper intraoperative evaluation and

Table 22.1 Indications for percutaneous antegrade ureteroscopy.

Large, impacted upper ureteric stone
Simultaneous kidney stones
Failure of retrograde ureteroscopy (URS) or extracorporeal shock-wave lithotripsy (ESWL)
Presence of distal ureteric stricture or severe tortuosity
Presence of urinary diversions

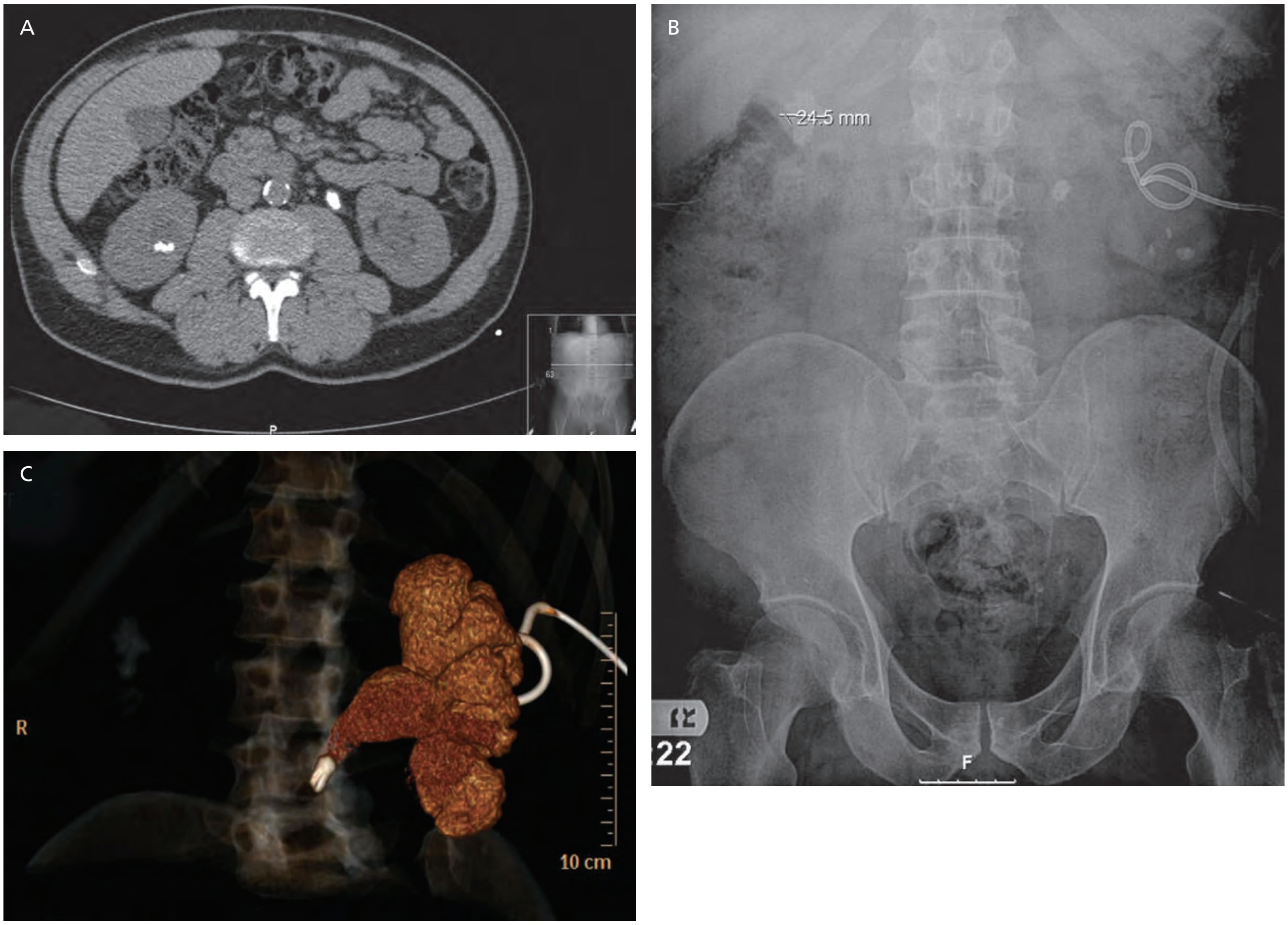

Figure 22.1 Upper ureteral impacted stone and complete obstruction. (A) Noncontrast computed tomography with left hydronephrosis and upper ureteral stone. (B) Upper ureteral stone on kidney, ureters, and bladder X-ray with left nephrostomy placed in the lower pole. (C) 3D reconstruction of antegrade pyelography demonstrating stone impaction with complete obstruction.

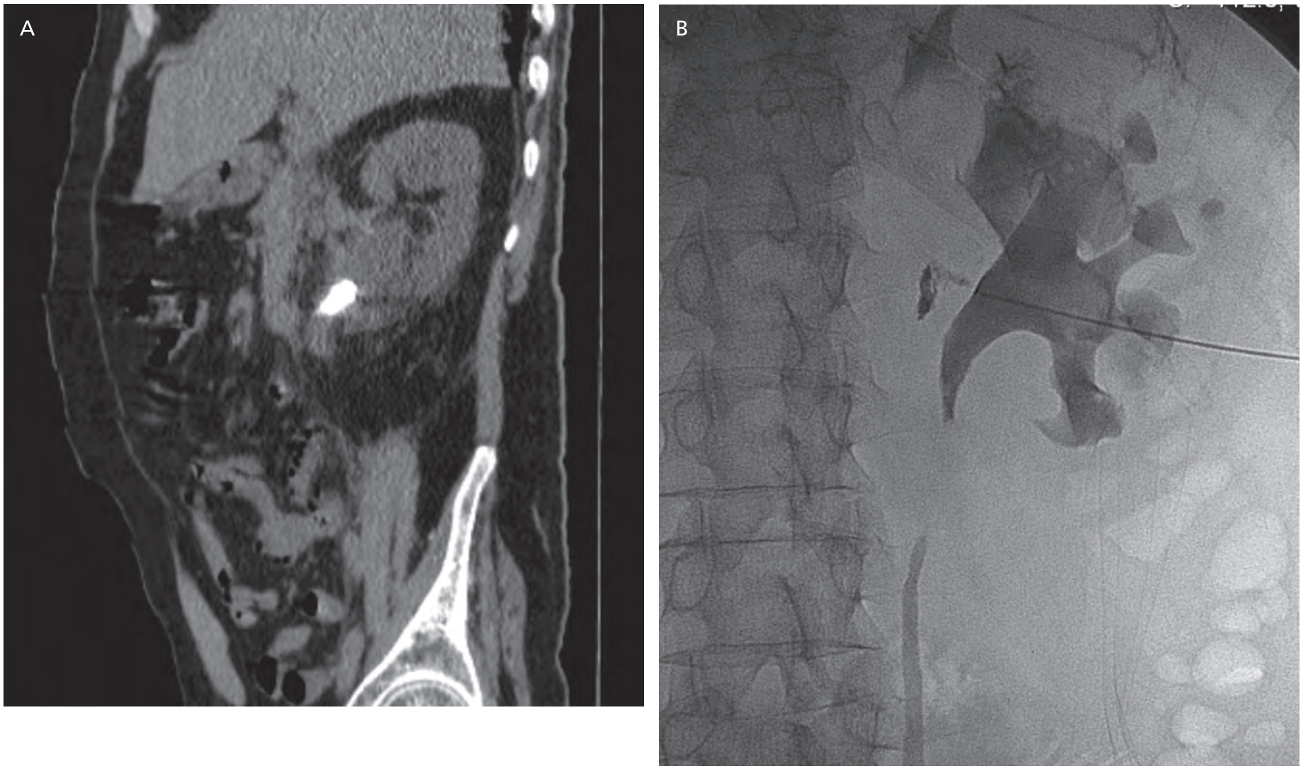

Figure 22.2 Upper ureteral stone obstruction. (A) Noncontrast computed tomography with large radiolucent impacted stone. The stone is not seen on kidney, ureters, and bladder X-ray. (B) Antegrade pyelography demonstrating upper ureter with radiolucent stone impaction.

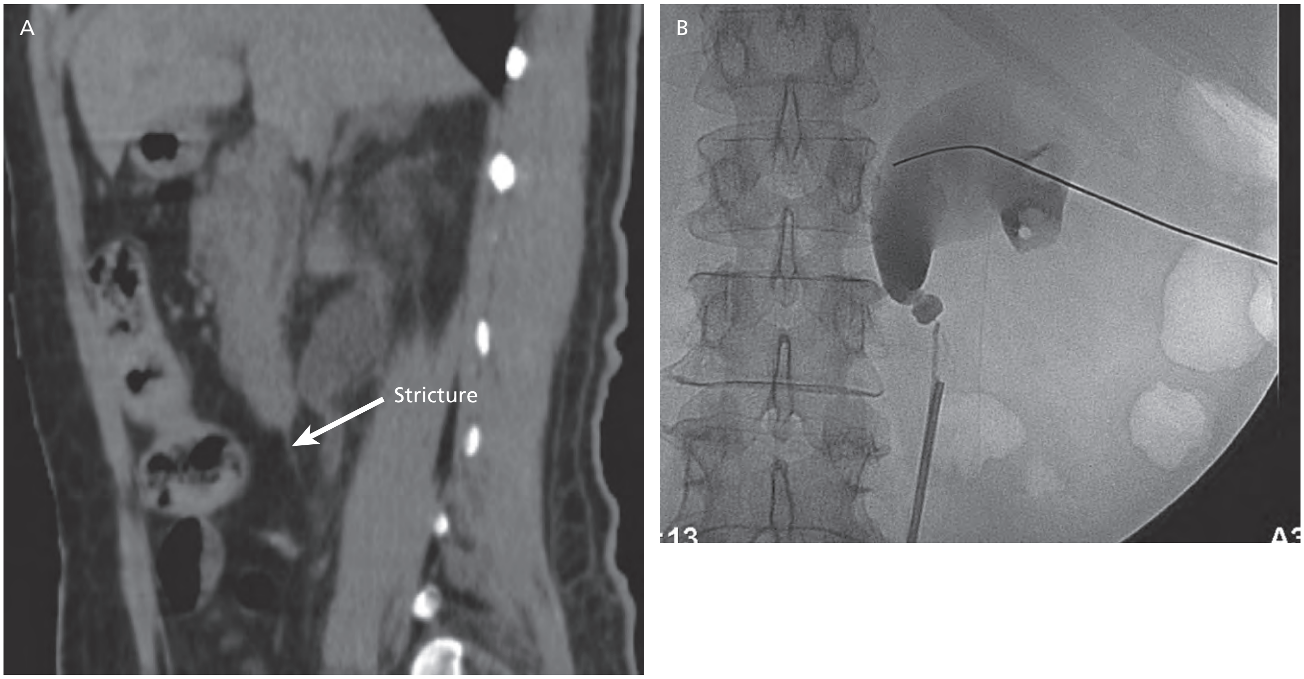

Figure 22.3 Upper ureteral stricture. (A) Noncontrast computed tomography with dilated renal pelvis and stricture (arrow) in the upper ureter. (B) Combined antegrade and retrograde pyelography with upper ureteral stricture.

treatment undertaken. [22] A prior nephrolithotomy or percutaneous nephrolithotripsy could indicate a more challenging percutaneous access due to perirenal fibrosis, scar formation, or calyceal infundibular stricture. Gaining access in such cases can require metal dilator sets.

General patient status focuses on assessing cardiovascular and pulmonary tolerance to prolonged prone position, anemia and coagulation disorders, renal function, and current and previous urinary tract infections (UTIs). Anesthetic clearance should be obtained for patients with known cardiovascular or pulmonary disease and UTIs should be treated accordingly. Pulmonary function tests are helpful to access the feasibility of the face-down position, especially in obese patients. The supine position is a desirable alternative for severely obese patients or those with chronic obstructive pulmonary disease (COPD); and a semirotated torso positioning allows for a combined antegrade and retrograde approach [23, 24]. A preoperative nephrostomy can save time in such instances. Warfarin should be stopped or the patient switched to low molecular weight heparin with anticipation; the last dose of the latter should be administered 12 h prior to the procedure.

In patients with impaired renal function or parenchymal loss apparent on CT, nuclear renal scintigraphy should be obtained. A static renal scan (DMSA) can precisely assess differential renal function even in the presence of obstruction [25–27]. If split kidney function is less than 15% and does not improve with renal drainage then laparoscopic nephrectomy with ureterectomy below the stone level is advisable instead.

The patient is left on nil per os (NPO) from midnight the evening prior to the procedure, and blood type and cross-matching are obtained should transfusion be required. Autologous blood donation is not cost-effective, and routine bowel preparation is not performed, as bowel injury is infrequent [28, 29].

Surgical technique and instrumentation (Table 22.2)

After induction of general anesthesia, the patient is placed in the lithotomy position and a 6F open-ended ureteral catheter is inserted up to the renal collecting system under fluoroscopy to assure uncomplicated ureteral catheter access to the collecting system. This also can be achieved with a flexible cystoscope and in the prone position. If there is no passage, then the ureteral catheter should remain below the stone or stricture for careful contrast injection, without causing any perforation. A retrograde pyelography can fill up the upper system to facilitate the kidney access. The ureteral catheter is connected to an extension tube and a Foley catheter is subsequently left in the bladder.

Table 22.2 Steps of percutaneous antegrade ureteroscopy.

Retrograde insertion of open-ended ureteral catheter
Posterior upper pole or mid–upper pole puncture
Insertion of thin Amplatz sheath or ureteral access sheath up to the level of the stone
Flexible or semi-rigid ureteroscopy
Flexible nephroscopy if the stone is just below the ureteropelvic junction (UPJ)
Laser lithotripsy and basket extraction
Tube or tubeless as evaluated intraoperatively

The patient is turned to the prone position, carefully padded, and a hard-surface pillow is placed under the abdomen to allow proper chest expansion (see Video 22.1). If the patient harbors a nephrostomy tube (usually placed due to sepsis or renal function impairment), a ureteral catheter is not needed as the nephrostomy tube can be used to inject contrast into the collecting system; only a Foley catheter in the bladder is necessary. After sterile preparation, a mixture of contrast and/or air is injected through the ureteral catheter to aid in the identification of the most suitable posterior calyx for puncture. If retrograde pyelography is not feasible, then access is obtained under ultrasound guidance. If rigid instruments are used, the selected calyx must allow straight alignment with the ureteropelvic junction (UPJ). This is usually accomplished by puncturing an upper or mid–upper calyx [30, 31] with an 18G Chiba needle. After entry into the chosen calyx is confirmed, a floppy-tip 0.035-inch hydrophilic wire is coiled in the collecting system, the skin is incised, and the needle shaft removed. Examples of appropriate guidewires for gaining access are the Roadrunner (Cook Medical, Bloomington, IN, USA) and glidewire (Terumo Medical, Somerset, NJ, USA). Hydrophilic guidewires with a floppy tip and rigid shaft (although some are slippery) can also be used, and include the Sensor guidewire (Boston Scientific, Natick, MA, USA) and stiff shaft glidewire (Terumo Medical).

The tract is sequentially dilated with 6F, 8F, and 10F fascial dilators. Should the wire not go down the ureter, an attempt to guide the wire down to the ureter is made with a 6F angiographic catheter. If successful, the floppy wire is replaced by a super-stiff wire and coiled in the bladder. If unsuccessful, no force should be exerted as this may result in unnecessary and disturbing bleeding or perforation. A second wire should be placed and coiled in the renal pelvis or calyx for safety. If the aim is to dilate up to 30F, balloon or Amplatz dilators are equally effective [32, 33]. In most cases a mini-access sleeve is needed; an 18–20F access sleeve is sufficient for a ureteroscope or flexible nephroscope (see Video 21.1). We usually dilate up to 18F when using just a flexible nephroscope, and 12–14F when using just a flexible ureteroscope. While stones located in the upper ureter near the UPJ can be reached with a flexible nephroscope or semi-rigid ureterosope, those located more distally require especially flexible ureteroscopy. In the case of a unique ureteral stone with no concomitant renal stones, we usually use a flexible ureteroscope, and advance a 12F ureteral access sheath down to the ureter to gain safe direct ureteral access. If a previous nephrostomy tube was placed for acute reasons, the tract can be used to access the collecting system. However, the procedure should be performed only after the acute state has been resolved, usually about a week later. Flexible scopes are required to access the ureter if the nephrostomy tube was placed through a lower pole calyx. When a straight approach to the UPJ is desired, a new upper or mid–upper pole puncture is required. In such cases, use of the nephrostomy tube to fill the collecting system with contrast and air can aid in the selection of the best calyx for puncture. Direct and straight access to the UPJ is crucial, and thus should not be compromised by using the pre-existing nephrostomy tract.

Lithotripsy can be performed with different modalities, including ultrasonic, mechanical, and laser energy. While ultrasonic lithotriptors enable concomitant fragmentation and suction, they can be deployed solely through semi-rigid endoscopes. Lasers on the other hand, can be deployed either through rigid or flexible scopes, and are the preferred modality with small-diameter flexible ureteroscopes. Fragments are extracted with graspers or baskets. Nitinol-covered baskets deployed through flexible scopes are recommended as they least impede scope deflection. We perform ureteral lithotripsy with a holmium:YAG laser and a 200-μm fiber when working with a flexible ureteroscope, and with 365-μm fiber or mechanical lithotripter (Lithoclast, EMS) when working with a semi-rigid scope or flexible nephroscope. Special care should be taken to clean all stone fragments in the obstructed area (see Video 21.1), since residual stone material can aggravate stricture formation. A ureteral dilator is passed down the ureter over a guidewire following stone removal to ensure appropriate ureteral caliber. If ureteral stricture is detected, an endoureterotomy using the holmium laser is feasible, set at a higher frequency and intensity than the lithotripsy set-up.

The need for postoperative drainage is evaluated intraoperatively [34]. If the patient is a candidate for a "tubeless" procedure, we place a double-J stent antegradely [35, 36] with stitch closure of the puncture site (see Video 21.1); if not, a re-entry percutaneous nephrostomy can be used for rapid reaccess to the ureter, or a Nephro-stent. If needed, we leave a 5F ureteral catheter down the ureter through an 18F Foley catheter with a hole in the tip located at the renal pelvis, for drainage and antegrade pyelography, or re-entry access.

Postoperative care

The retrograde ureter catheter can be removed postoperatively. The patient resumes a regular diet the same or next day, according to tolerance. If a tubeless procedure was performed, the patient is discharged on postoperative day (POD) 1 and stent removal is scheduled approximately 10 days later. If only a nephrostomy tube was left in, an antegrade nephrostogram is performed on POD 2 and the nephrostomy removed upon assurance of contrast passage to the bladder.

Results

Contemporary stone-free rates for percutaneous antegrade treatment of ureteral stones are at least 86% [37–39]. In a randomized trial of patients with upper ureteral stones of greater than 1 cm in diameter, Sun *et al*. found a significantly higher stone-free rate with the antegrade approach than with retrograde ureteroscopy (100% and 86% respectively, $P = .03$) [37]. A randomized study of 150 patients with upper ureteral stones of 1.5 cm or greater in diameter found no significant differences in stone-free rates between retrograde ureteroscopy, laparoscopic ureterolithotomy, and percutaneous antegrade ureteroscopy (76%, 90%, and 86% respectively, $P = .06$) [38]. The low statistical power of the study may be the reason for the lack of statistical significance, despite the trend.

A retrospective study of antegrade percutaneous ureteroscopy for upper ureteral stones of greater than 1 cm in diameter in 192 patients with severe hydronephrosis reported a 5% stricture rate [39]. A reported 44% stricture rate for retrograde ureteroscopy for upper ureteral stones was mostly due to ureteral injury and failure to completely release all stone fragments from the ureteral wall [22].

Conclusions

With high stone-free rates and minimal complications, percutaneous antegrade ureteroscopy is an excellent option when URS or ESWL are not suitable or have previously failed. Nevertheless, close postoperative follow-up is important to ensure early identification of ureteral strictures, regardless of the approach selected.

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CHAPTER 23

Special Problems with Staghorn Calculi

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Introduction

Staghorn calculi require definitive surgical management in order to prevent the potential consequences of renal deterioration from long-term obstruction and recurrent urinary tract infections (UTIs) and sepsis. According to the American Urological Association (AUA) guidelines panel (2004), complete stone removal should be the therapeutic goal, and percutaneous nephrolithotomy (PCNL) monotherapy has emerged as the treatment of choice for the majority of patients with staghorn calculi [1].

Varying percutaneous techniques have been developed with the goal of maximizing stone clearance while maintaining patient safety. Modifications have been described in patient positioning [2], site and number of percutaneous access tracts [3], and instrumentation used for endoscopy, stone fragmentation, and stone removal [4].

In addition to the steep learning curve required to perform PNCL, specific circumstances, including previous urinary tract surgery, paraplegia, and coagulopathy, can make complete stone removal more challenging. Significant stone burden can make both access and stone removal more technically demanding. Active infection can also be encountered unexpectedly, and this must be addressed in order to maximize patient safety.

This chapter will focus on patient- and stone-related variables that can complicate successful PCNL, review the varying described techniques used to overcome these challenges, and review our own approach in treating difficult staghorn calculi.

Preoperative evaluation

All patients scheduled for PCNL undergo standard preoperative laboratory testing and cardio/pulmonary evaluation based on age and pre-existing medical conditions. Preoperative urine cultures are mandatory to identify specific pathogens that can guide perioperative antibiotic coverage. These cultures are often difficult to interpret as many patients have indwelling ureteral stents or nephrostomy tubes already in place. Treatment of symptomatic patients with culture-specific oral antibiotics is mandatory prior to an elective procedure and we routinely treat asymptomatic patients with positive urine culture results to sterilize the urine prior to urologic instrumentation [5]. Patients who have unusual or resistant pathogens may require preadmission hospitalization for intravenous antibiotics prior to definitive therapy. Specific parameters regarding agent of choice and duration of perioperative therapy are often made in conjunction with our infectious disease colleagues. For asymptomatic patients with negative or colonized culture results, broad-spectrum antibiotics with adequate urinary tract penetration are preferred. In our practice, we most often utilize combination therapy with ampicillin (1–2 g) and gentamicin (5–7 mg/kg) to provide both Gram-positive and Gram-negative coverage. Alternatively, quinolones provide adequate coverage of urinary pathogens and can be used for patients with penicillin allergies. Cephalosporins can also be used in patients with mild penicillin allergies or in patients with renal insufficiency.

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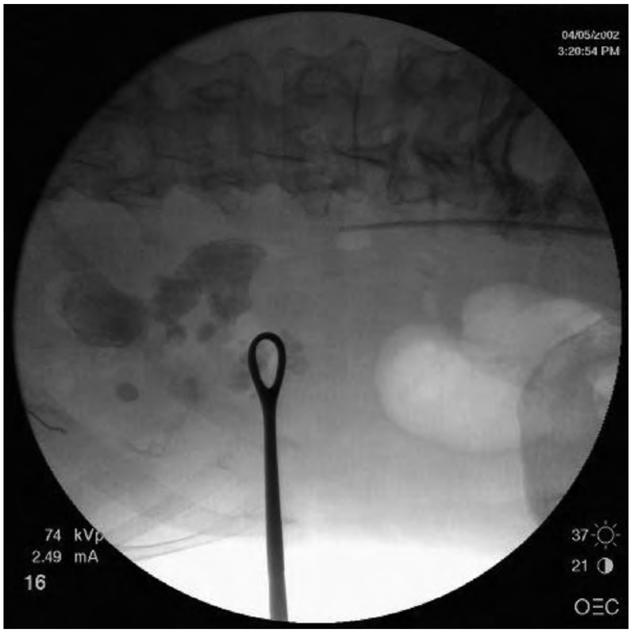

Figure 23.1 Air nephrogram used for identification of a posterior calyx.

Access

We perform all PCNL in the prone position using a split-leg table to provide access to the bladder. Flexible cystoscopy is performed and a guidewire is positioned in the renal pelvis under fluoroscopic guidance. A ureteral occlusion balloon (Boston Scientific, Natick, MA, USA) is then placed, followed by a Foley catheter to drain the bladder. The guidewire is removed and the posterior calyces are then outlined using air injected through the occlusion balloon to produce an air nephrogram (Figure 23.1). Normal saline irrigation is then instilled through the ureteral occlusion catheter to fill the collecting system and create a "pseudo-hydronephrosis." An access point (most commonly a posterior calyx) is then chosen based on stone location and overall burden to facilitate the most direct path to treat the stone burden.

After a site is chosen, percutaneous access is obtained using a standard triangulation method with an 18G Chiba needle. Access is confirmed using fluoroscopy as well as with the return of air and irrigation fluid from the needle lumen. A guidewire is then advanced into the renal pelvis with the primary goal of obtaining access into the bladder. Difficulties advancing the guidewire down the ureter can be encountered due to significant stone burden or stone impaction, most commonly at the ureteropelvic junction. In these situations, ureteral access may not be possible, and as an alternative, redundant guidewire is "curled" in the renal pelvis to facilitate tract dilation. Tract dilation can be performed via single-step balloon dilation or serial sequential dilation with either metal or Amplatz dilators [6]. In our institution, we currently use the X-Force N-30 (Bard, Covington, GA, USA) balloon dilation catheters. Tracts are dilated to 30 atm, and occasionally, fascial incising needles are needed secondary to dense scar tissue in order to achieve full tract dilation. Balloon dilation is the preferred method of tract dilation at our institution in an effort to decrease the risk of bleeding that has been associated with sequential dilation [7, 8]. In our recent review of 225 patients using balloon dilation for single tract access, the mean decrease in hematocrit was 6.1 ± 4.3%, and only three patients required perioperative blood transfusion [9].

In situations where there is limited space due to a large stone burden, it is imperative to carefully position the balloon so that it remains in the collecting system without displacing the stone, losing access, or perforating the collecting system. There are also circumstances in which a staghorn calculus fills the entire collecting system, leaving no suitable area to gain access. In these situations, we often proceed with prone flexible ureteroscopy. Stone is cleared to access a posterior, upper or mid pole calyx, using holmium laser lithotripsy. The ureteroscope can then be used to guide and visualize the needle entering the chosen calyx.

Urologist versus radiologist obtained access

The decision process in selecting the ideal calyx for access is fundamental in achieving the goals of maximal stone clearance and procedure safety. Often, preoperative or perioperative access is obtained by interventional radiologists for various reasons, including acute obstruction and/or infection, patient body habitus, atypical renal anatomy, prior urologic intervention/reconstruction, or surgeon preference. A survey from the University of Iowa in 2003 found that only 11% of urologists performing PCNL routinely obtained the percutaneous access [10].

A recent study from our institution compared outcomes and complications of access obtained by urologists and interventional radiologists in 233 patients undergoing PCNL [11]: 39% of the stones in the urologist access group were classified as staghorns versus 30% in the radiologist group. The complication rates were similar between groups, but the overall stone-free rate was significantly greater in the urology access group (99% vs 92.1%, $P = .03$). In cases of access performed by radiologists, additional urologist-obtained access was required in 36.8% of the cases. This is difficult to interpret as the primary goal of radiologist-obtained access was often to relieve acute obstruction, and not to facilitate future therapeutic management. Regardless, urologist-obtained access in high-volume stone centers can facilitate stone-free rates, ranging from 83% to 86%

[12, 13], even in the presence of very large stone burdens or staghorn calculi.

Supporting this notion, in a large retrospective series comparing PCNL outcomes in 1121 patients, El-Assmy *et al*. reported that between the urologist access group and radiologist access group stone-free rates (83.4% and 86.1%, respectively) and complication rates, except for bleeding (4.3% and 2.1%, respectively), were similar [12]. However, they observed that urologists utilized multiple (18.1% vs 0%) or supracostal tracts (16.9% vs 4.7%) more frequently, and concluded that urologist-obtained access is safe and effective even in cases of large or complex stone burdens.

Access location

Choice regarding the ideal calyx for percutaneous access is dependent on patient anatomy, stone burden, and individual surgeon preference. Accessing the upper pole allows for direct access to the majority of the collecting system as well as the upper ureter. This location is often necessary to treat staghorn calculi, large renal pelvic stones, and upper ureteric calculi [14, 15]. Upper pole access can be achieved via a subcostal or supracostal approach. Supracostal entry is usually in the 11th intercostal space. Although the upper pole often provides the most direct access to treat large or complex stone burdens, there is an increased risk of pulmonary complications, including hemothorax, hydrothorax, and pneumothorax, especially if an intercostal approach is utilized [15].

Several groups have examined the safety and efficacy of supracostal upper pole access [14–17]. They agree that this approach provides for excellent stone clearance while maintaining patient safety. In these large series, pulmonary complications ranged from 5% to 15%. When complications did arise, they were usually managed conservatively. In a comparative report, Lang *et al*. examined stone-free and complication rates utilizing both subcostal and supracostal percutaneous access [17]. Of 103 patients undergoing PCNL with intercostal access; 91 (88%) were rendered stone free, four had major complications, and six had minor complications. These results were compared to 39 patients with subcostal access; 29 (74%) were stone free, three had major complications, and eight had minor complications. From these data the authors concluded that intercostal access should be the route of choice for upper pole PCNL due to the low complication rate, high stone-free rate, and reduced operating time.

Lojanapiwat and Prasopsuk found that the supracostal and subcostal approaches were both effective with acceptable complication rates [14]. However, they observed a higher rate of pulmonary complications (15.3% vs 1.4%, $P < .001$ value) in patients undergoing supracostal access. Based on the potential for pulmonary complications, they recommend proceeding with a supracostal approach only in appropriately selected patients. Postoperative monitoring and chest imaging should be mandatory in these cases.

Single versus multiple access tracts

Treatment of complex or staghorn calculi can be approached with multiple percutaneous tracts during a single operative procedure [18, 19] or with a single tract approach in combination with flexible instrumentation [20]. It is controversial as to which of these approaches offers superior stone clearance while minimizing patient morbidity.

Utilizing multiple tracts in a single session is advocated by some authors because it is often difficult to access all of the renal calyces to treat the entire stone burden through a single tract. Stone-free rates in various series using multiple tracts are above 80% [19]. Described by Desai *et al*., main tract access is obtained via ultrasound guidance and is the site through which maximum stone burden can be cleared [18]. Additional supplemental tracts are placed for residual peripheral calyceal stones. Guidewires are placed to stabilize the tracts and the main tract is dilated to place a 26F or 28F Amplatz sheath. Secondary tracts are dilated later in the procedure to 20–24F. Lithotripsy is maintained for 90 min and a second stage is performed 48–72 h later if necessary.

Despite the potential advantages of improved stone clearance and less hospital cost with a single procedure, there are concerns with utilizing multiple percutaneous access points as well. The primary concern is for increased risk of intraoperative or postoperative hemorrhage and subsequent need for blood transfusion. Blood transfusion rates range from 3% to 45% in the literature with multiple tract access [19], although transfusion requirements have been shown to decrease with increasing surgeon experience [21]. Attempts to minimize the risk of bleeding have been addressed by limiting sheath size and dilating the secondary tracts later in the procedure only if needed. Guohua *et al*. describe a modification of multiple tract technique utilizing tracts dilated to 14–18F [22]. Using this approach, they obtained a stone clearance rate of 93% with a 3% transfusion rate.

Despite higher transfusion rates with the multitract approach, the risk of other major complications does not seem to significantly differ when compared to single tract procedures [18, 23]. Hegarty *et al*. have published the only study to date comparing the morbidities of these two approaches [23]. They reviewed 20 patients in each group and found that despite a higher transfusion rate in the multitract cohort, the mean drop in hemoglobin was similar between groups. They attribute this to the fact that the patients in the multitract group had significantly lower baseline hemoglobin values. Bleeding can usually be managed conservatively, leading the proponents of this procedure to conclude that it is both safe and effective. Other proposed advantages include avoiding the increased cost and learning curve associated with the flexible instrumentation required in the single tract approach [19].

Large stone burdens can also be approached with a single access tract due to the technologic advances in flexible instrumentation, lasers, and basketing devices. This approach has been described by several endourologists [20] and is currently the procedure of choice at our institution. The access site is carefully chosen to provide access to the majority of calyces. Usually this is via the upper pole calyx, which enables the surgeon to access the majority of the collecting system. The most common access sites are either below the 12th rib or between ribs 11 and 12. After obtaining access and tract dilation, rigid nephroscopy is utilized to clear as much stone burden as possible, while minimizing renal parenchymal trauma. Our preference is to use the Lithoclast Ultra (Boston Scientific), which combines pneumatic energy to maximize stone fragmentation with ultrasonic energy to suction, remove stone fragments, and improve intraoperative visibility (Figure 23.2). Intracorporeal lithotripsy is an essential component of PCNL, especially when treating large stone burdens. The commercially available devices include ultrasonic and pneumatic devices, or a combination of the two. The advantage of the combination lithotripters is their ability to fragment stones of varying compositions while concomitantly evacuating stone debris. This avoids the time-consuming process of manual stone fragment removal [4]. The remaining stone burden is then approached with flexible instrumentation (Figure 23.3). Calculi that are small enough are removed with a stone basket via a flexible cystoscope or ureteroscope. Larger or impacted stones are fragmented with the holmium laser and then either removed with a stone basket or positioned so they can be treated with the rigid nephroscope.

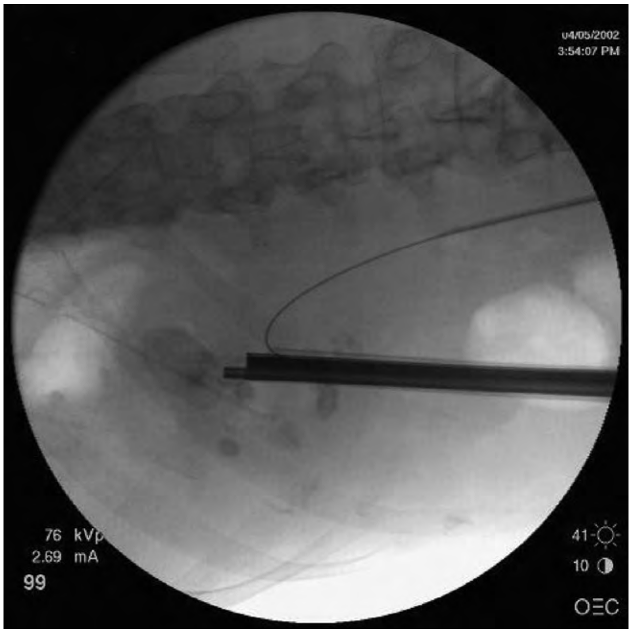

Figure 23.2 Use of the Lithoclast Ultra (Boston Scientific, Natick, MA, USA) for rigid nephrolithotripsy.

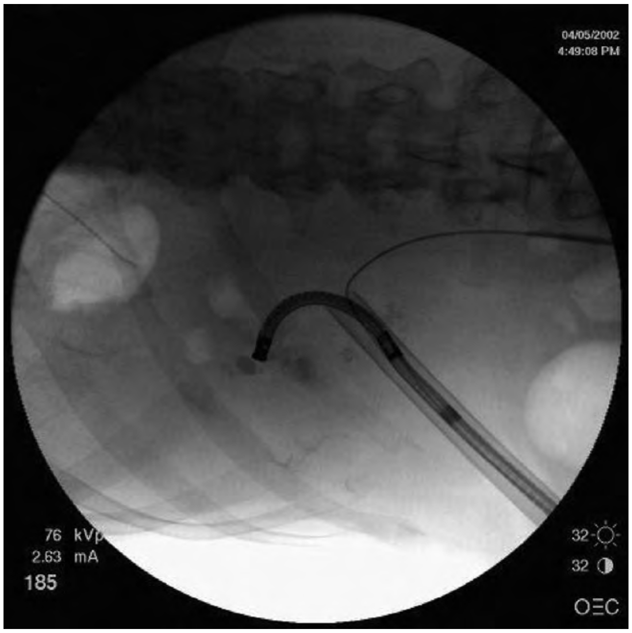

Figure 23.3 Use of the flexible cystoscope to treat remaining stone after rigid nephrolithotripsy.

At the conclusion of the procedure, we routinely leave either a single or double J ureteral stent. Historically, a large bore nephrostomy tube (22F council-tip catheter) was routinely placed to externally drain the kidney, maintain percutaneous access, and tamponade renal parenchymal bleeding. Now, a nephrostomy tube is placed only when there is concern for bleeding and residual stone at the conclusion of the primary procedure. The nephrostomy tube maintains the tract for second look nephroscopy. When there is minimal concern for bleeding or residual stone necessitating a second look procedure, our preference is to leave patients without a nephrostomy tube. While controversial, “tubeless” PCNL has been shown to be safe and effective while decreasing analgesia requirements and length of hospital stay [24, 25]. Recently, investigators have questioned the practice of tubeless PCNL. They prospectively studied patients undergoing tubeless PCNL versus early nephrostomy tube removal, and found no differences in analgesia requirements, mean decrease in hemoglobin, or hospital stay [26]. It is important to consider that complete stone removal may not always be achieved despite perceived on-table stone clearance, and maintaining the tract with a nephrostomy tube for second look nephroscopy may be beneficial.

If required, the timing of second look nephroscopy depends on primary surgeon preference. In a series of 45 renal units with a stone burden of 5 cm or greater undergoing single tract access, Wong and Leveillee reported a stone-free rate of 95%. This required a mean of 1.6 (range 1–3) procedures and second look nephroscopy was performed at 1 week when needed [27]. In our practice, a noncontrast computed tomography (CT) scan is obtained on the first postoperative day if there is suspicion of residual stone following the primary procedure. If residual stone is present, and the patient was left with a nephrostomy tube to maintain access, second look nephroscopy is performed on postoperative day 2 during a single hospital admission. If the patient was left tubeless, and residual stone is found, it can be approached with second-look retrograde ureteroscopy during the same hospitalization or at a later date depending on patient or surgeon preference.

Percutaneous access utilizing ureteroscopic assistance

Large stone burdens can make obtaining access difficult as there may not be sufficient space to enter and safely dilate a tract. If access can be achieved, and a tract is safely dilated, it may still be difficult to reach the entire intrarenal collecting system through a single tract despite the use of flexible instrumentation. To address these issues, retrograde ureteroscopy has been utilized to identify the ideal calyx for percutaneous entry [28, 29]. Ureteroscopy can be performed initially to assess the stone burden/location and to endoscopically clear a calyx to provide optimal access. Once identified and any obstructing stone burden cleared with retrograde lithotripsy, the access needle can be placed and confirmed under direct ureteroscopic vision [30]. Use of a ureteral access sheath can facilitate retrograde lithotripsy, which can be performed with the patient in either the supine or prone position. If done with the patient in the prone position, it is feasible to perform simultaneous retrograde and antegrade lithotripsy to maximize stone clearance (Figure 23.4).

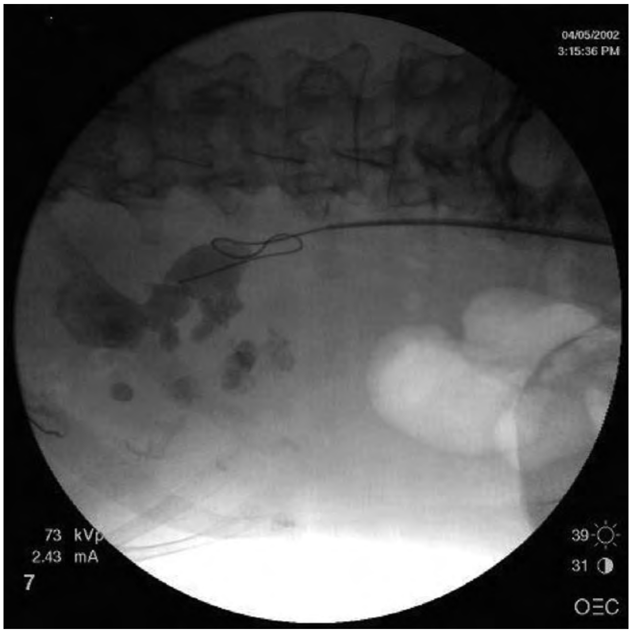

Figure 23.4 Retrograde wire placement for initial prone ureteroscopy.

Supine versus prone percutaneous nephrolithotomy

Recently, there has been interest in the optimal patient positioning to maximize stone-free rates while minimizing the risk for position-related complications. This has resulted in an evolving debate comparing the outcomes of traditional prone PCNL with a modified supine position (Galdakao-modified supine Valdivia position) [31–33] (see Chapters 10 and 11). Proponents of the supine position stress the potential anesthesia advantages, particularly in obese patients, where the prone position can limit respiratory capabilities. Other perceived advantages include improved patient comfort and increased versatility of stone manipulation. Access is usually subcostal via a posterior lower pole calyx, which minimizes the risk for pleural injury. In addition, it has been stressed that by maintaining the supine position, retrograde ureteroscopy can be performed in addition to standard antegrade treatment. Ureteroscopy can be done prior to PCNL or simultaneously, and does not require patient repositioning which can be both time consuming and lead to increased pressure-related and neurologic injuries [32]. Scoffone *et al*. recently described their experience with endoscopic combined intrarenal surgery in the modified supine position. Their stone-free rate for 127 patients after a single procedure was 81.9%, and increased to 87.4% after a second look procedure. The mean stone size was 23.8 mm, and 33.1% were classified as partial or complete staghorn calculi. Their results led the authors to conclude that this approach was both safe and effective with an overall complication rate of 38.6%, which is in range with the current literature for PCNL [33]. No adjacent organ injuries, pleural injury, kidney loss, or deaths were reported.

Proponents of the prone position focus on the familiarity of the patient anatomy as well as decreased renal mobility facilitating percutaneous access. A comprehensive review of the literature by de la Rosette *et al*. concluded that prone PCNL is associated with decreased operative times, similar bleeding rates, and slightly improved stone-free rates for obese patients and staghorn calculi when compared to the supine approach

[31]. The only prospective randomized trial, by De Sio *et al.*, found similar stone-free and complication rates between the two approaches, but their cohort excluded complicated and staghorn calculi, which limits the interpretation or applicability of their results [32].

To utilize the advantage of concomitant retrograde ureteroscopy, it is our preference to perform ureteroscopy in the prone position when required. Using a split-leg table, the patient can be positioned to easily perform flexible cystoscopy and access the ureter. Prone endoscopy has a steep, but easily overcome, learning curve, and this skill can easily be obtained by any endourologist familiar with flexible instrumentation. The prone position can thus allow for both antegrade and retrograde stone manipulation without the need for patient repositioning.

To support the feasibility of prone retrograde ureteroscopy our group recently reviewed 35 patients who were scheduled for prone ureteroscopy with the possibility of PCNL; 80% of the patients were able to be managed ureteroscopically while the remaining patients required additional percutaneous lithotripsy to maximize stone clearance. Of those treated only with retrograde ureteroscopy, 82% were rendered stone free. The seven patients requiring simultaneous PCNL were all stone free upon completion [34]. There were no serious complications in either group. It is now our practice to offer this approach for patients with characteristics that place them at high risk for morbidity with PCNL, including morbid obesity, previous urinary tract reconstruction, and paraplegia, or for patients who may be amenable to retrograde clearance, but in whom stone size, composition, and location may dictate an “on the table” decision.

Obesity

It has been theorized that PCNL in obese patients might be associated with lower efficacy or higher complication rates when compared to patients of normal weight. General anesthesia is one concern due to the limited respiratory pattern while patients are maintained in the prone position. Instrument size limitations pose potential technical concerns. The X-Force N-30 (Bard) balloon dilation catheters routinely used at our institution provide access sheath lengths of 17 cm or 22 cm. The working length of our longest rigid nephroscope is 24 cm. If the distance from the patient’s skin to the desired access calyx is beyond these lengths, both access safety and efficacy of stone clearance can be significantly hampered. We routinely measure this distance using preoperative CT imaging to estimate whether our instruments can be effectively used. If the estimated distance is too long, staged flexible ureteroscopy will be the treatment recommendation.

While some early series reported higher complication rates and longer hospital stays in obese patients [35], the majority of studies have shown similar efficacy and complication rates for obese and normal weight patients [36–40]. In a recent review of our own institutional experience in 234 patients, stone-free rates, complication rates, blood loss, and length of hospital stay were all found to be independent of body mass index (BMI) [40]. The consensus from the majority of the published literature is that obesity in itself should not be a contraindication to a percutaneous approach in the hands of well-trained endourologists.

Infected systems

An important consideration in the management of complex stone burdens, especially staghorn calculi, is the presence of active infection. Preoperative work-up must always include urine culture and sensitivities, and when positive, complete treatment prior to surgery to sterilize the urine. Often this can be done as an outpatient with oral antibiotics; however, some patients can have resistant species of bacteria or fungi that require intravenous therapy. These patients may require preadmission and consultation with infectious disease specialists prior to definitive intervention. Since PCNL is most often an elective procedure, it is well established that patients with symptomatic UTIs should not undergo endourologic intervention due to the risk of septicemia. Such patients need to complete a full course of preoperative antibiotic therapy tailored to individual organisms and in some cases drainage of the infected/obstructed systems prior to definitive stone management.

Unfortunately, it is not possible to identify all patients at risk of infectious sequelae based on preoperative cultures and imaging. To further complicate this, purulent fluid may be encountered when the collecting system is entered during PCNL access. This can occur in asymptomatic patients with negative urine cultures. While the initial response would be to abort the procedure and drain the system due to the risk of urosepsis, the significance of encountering purulent fluid in an asymptomatic patient is unclear. Two groups of investigators recently examined this issue with the hypothesis that not all purulent fluid represents active infection [41, 42]. They postulated that in specific circumstances this phenomenon may represent a sterile inflammatory response to the presence of the stone or stone debris itself. Both groups retrospectively compared patients whose procedure was completed at the time of encountering purulent fluid versus those who were drained and treated at a later date. The incidence of urosepsis did not differ between the two groups, and Hesseini *et al*. concluded that PCNL can be performed in the same setting with appropriate antibiotic coverage [42]. Aron *et al.* further identified risk factors for sepsis which included recent history of febrile UTI, borderline elevation of total leukocyte count, thick purulent fluid, use of a single tract or delayed creation of second tracts, and operating time greater than 90 min [41]. Despite these factors however, it remains impossible to predict which patients will progress to significant sepsis. Therefore, all patients must be closely monitored postoperatively whether the procedure is done in one setting or in a staged fashion. The optimal management of patients found to have purulent fluid on percutaneous access remains unclear without randomized studies. It is our practice to drain purulent systems and delay stone manipulation to a later time, even in asymptomatic patients. However, the optimal time period needed for collecting system drainage and antibiotics before stone treatment is unknown and currently determined by the judgment and experience of the primary surgeon.

Postoperative fever can often be the first clinical sign that patients may be becoming septic. However, while fever after PCNL is common, there is no direct correlation with progression to urosepsis and currently its clinical significance is unclear. It is clear that endoscopic stone manipulation can induce bacteremia, endotoxemia, and resulting sepsis in both healthy and immunocompromised patients. Cadeddu *et al*. recently reviewed patients undergoing PCNL with negative preoperative cultures who received prophylactic antibiotics. All patients who were febrile post PCNL remained hemodynamically stable with negative blood and urine cultures [43]. There was also no association with fever and stone composition. It therefore remains difficult to define patients who will become septic despite close postoperative monitoring.

Conclusions

PCNL for staghorn calculi or complex stone burdens can be technically challenging, even in the hands of experienced endourologic surgeons. Specific challenges include obtaining access, defining the optimal number and location of access tracts, the ideal patient positioning, and predicting and managing infectious complications. The goals of patient safety and efficacious stone removal remain clear. However, the ideal methods to achieve these goals are less clear and are the source of considerable debate. Future prospective studies comparing these techniques are necessary in order to provide definitive recommendations in the management of staghorn calculi. Until then, surgeon experience will remain the most important factor used to guide contemporary practice patterns with complex PCNL.

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CHAPTER 24

Percutaneous Lithotripsy and Stone Extraction

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Introduction

Currently, percutaneous nephrolithotomy (PCNL) employs four techniques for intracorporeal lithotripsy in clinical practice: electrohydraulic lithotripsy (EHL), ultrasonic lithotripsy, pneumatic lithotripsy, and laser lithotripsy (Figure 24.1). Each of these lithotripsy devices has inherent benefits and limitations to their utilization. PCNL remains the procedure of choice for most stones greater than 2 cm in size, complex staghorn calculi, some lower pole stones, stones within a caliceal diverticulum, and larger renal stones that are refractory to extracorporeal shock-wave lithotripsy (ESWL) [1].

Once a stone has been adequately fragmented, extraction is necessary in most situations. Several lithotripsy devices, specifically ultrasonic lithotripsy, have been paired with suction for simultaneous evacuation of stone fragments. In the majority of clinical situations, however, the surgeon is faced with the task of removing several stone fragments in a separate process. Fortunately, there are a number of devices (both rigid and flexible) created specifically for this purpose, including graspers, baskets, and stone cones. We have found that in most situations a zero-tip basket facilitates stone removal with the lowest risk of collecting system injury. During PCNL, however, the larger nephroscope facilitates the use of rigid graspers.

In this chapter we will provide an assessment of the different lithotripsy devices currently clinically available.

Electrohydraulic lithotripsy

In 1955 Yutkin, an engineer at the University of Kiev, invented EHL, [2]. The clinical use of this technology for intracorporeal lithotripsy was not reported until 1970 when Rouvalis reported the use of the Urat-1 EHL in 100 patients [3]. Its use was limited to bladder stones until 1985 when a 5F EHL probe was used in combination with a rigid ureteroscope to treat ureteral stones [4]. Since that time the development of smaller EHL probes has facilitated their use in flexible scopes.

The mechanism of action of the EHL probe is that of an underwater spark plug. The probe consists of two separate concentric electrodes of different voltage polarities. As current is applied, the resistance of the insulative gap eventually is overcome and a spark is produced. This spark in turn vaporizes the surrounding fluid, creating a cavitation bubble that expands and subsequently collapses [2] (Figure 24.2). A total of three shock waves are created through the process of rapid expansion, collapse, and rebound of the cavitation bubble [5]. Therefore, if the probe is held in direct contact with the stone, minimal water is vaporized and an inefficient shock wave is created. There are many electrohydraulic generators available and probe size is variable from 1.9F to 9F. Initially it was believed that optimal efficacy was achieved with EHL in a 1:6 normal saline solution. It was later determined, however, that EHL has equivalent efficacies in hypotonic and isotonic (normal saline) solutions [6].

The major disadvantage of EHL pertains to its narrow margin of safety. Unlike ESWL, the shock wave of EHL is not focused and the diameter of the cavitation bubble is dependent upon the energy settings used, with the propensity to expand to greater than 1.5 cm. Concern for collecting system injury led to several animal studies. In 1990 Bhatta *et al*. found that EHL was more likely than a pulsed dye laser to result in bladder perforation in a

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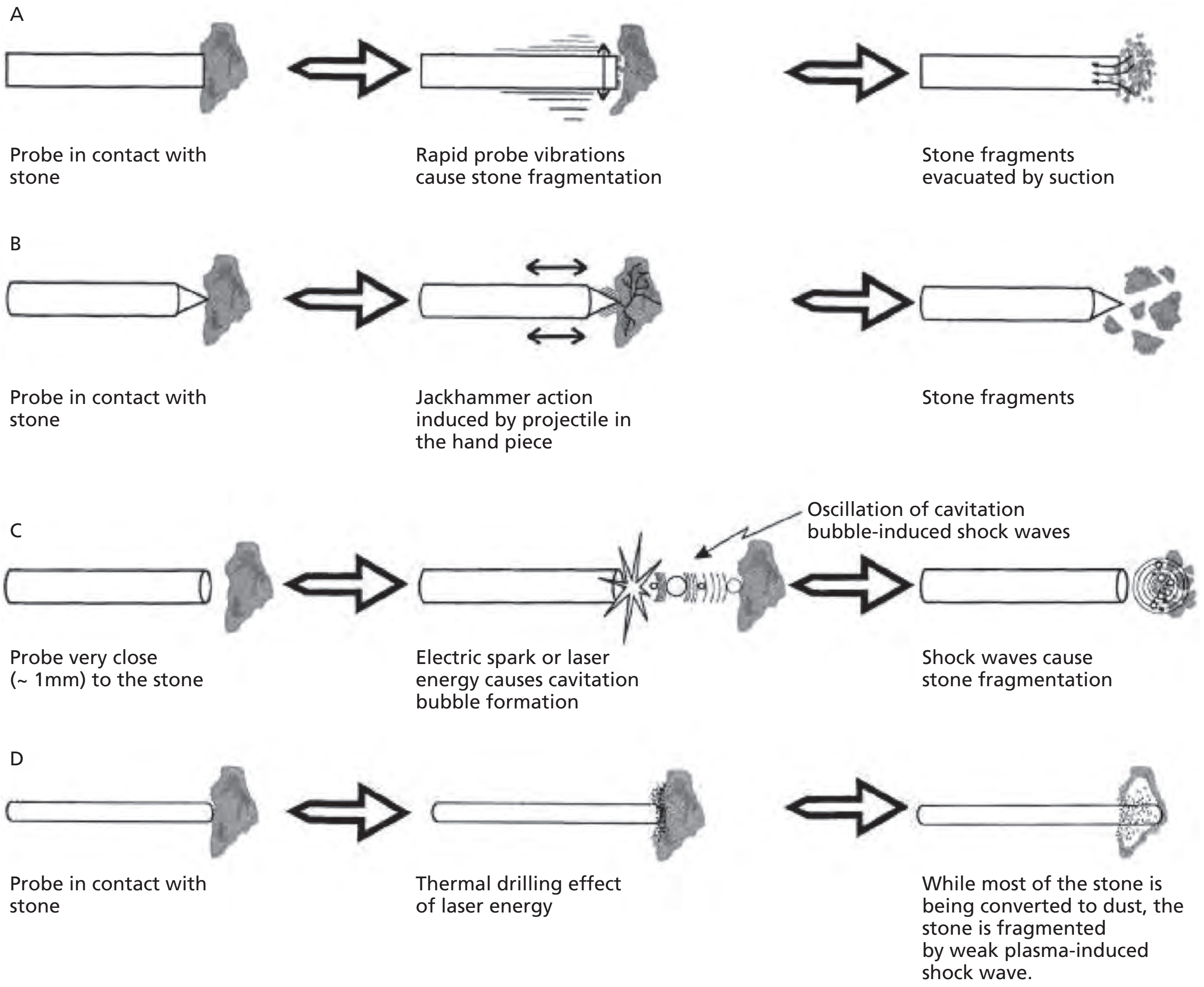
A
Probe in contact with stone
Rapid probe vibrations cause stone fragmentation
Stone fragments evacuated by suction
B
Probe in contact with stone
Jackhammer action induced by projectile in the hand piece
Stone fragments
C
Oscillation of cavitation bubble-induced shock waves
Probe very close (~ 1mm) to the stone
Electric spark or laser energy causes cavitation bubble formation
Shock waves cause stone fragmentation
D
Probe in contact with stone
Thermal drilling effect of laser energy
While most of the stone is being converted to dust, the stone is fragmented by weak plasma-induced shock wave.

Figure 24.1 Mechanisms of lithotripsy: (A) Ultrasonic, (B) pneumatic, (C) electrohydraulic lithotripsy, (D) laser (adapted from Zheng and Denstedt [13], with permission).

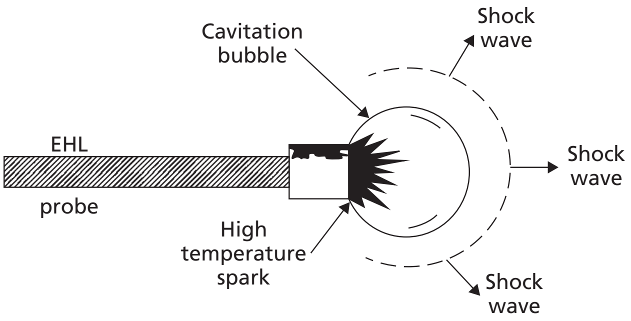
Cavitation bubble
Shock wave
EHL probe
Shock wave
High temperature spark
Shock wave

Figure 24.2 Mechanism of electrohydraulic lithotripsy (EHL) shock-wave generation (adapted from Grocela and Dretler [2], with permission).

rabbit model [7]. Similarly, in 1994 Piergiovanni *et al*. compared the effects of several lithotripsy devices on ureteral and bladder tissue in a pig model. These researchers demonstrated that EHL results in extensive tissue lesions secondary to heat [8].

In clinical practice, the development of smaller EHL probes has improved clinical safety, which has been extensively evaluated throughout the literature. Hofbauer *et al*. reported a perforation rate of 17.6% in a prospective study of 72 patients [9]. More recently, Basar *et al*. reported a 2.9% perforation rate in their experience treating 207 ureteral and renal stones with EHL [10]. Overall, ureteral perforation is noted to have a mean incidence of 8.5% [11].

In addition to safety concerns, another disadvantage of EHL is its propensity to propel fragments, as well as to create an ample number of fragments when large (>15 mm) stones are treated. In a series of 43 patients with a single ureteral stone proximal to the pelvic brim treated with EHL, 14% required subsequent ESWL to treat stones that had been inadvertently pushed into the renal pelvis [12].

Despite the concerns over safety and stone retropulsion, with experience EHL has been proven safe and effective. It is noteworthy that the smaller probes are flexible enough to allow their use with flexible ureteroscopes. In a series of 207 ureteral and renal stones treated with EHL, 90.3% were successfully fragmented with an 82.1% stone-free rate at 20 months follow-up [10]. Similarly Green and Lytton reported excellent fragmentation of 32 of 36 stones with the use of a 5F EHL probe [4]. Overall, the literature demonstrates a mean 90% fragmentation rate for ureteral stones treated with EHL [11].

In addition, EHL is the least costly method of intracorporeal lithotripsy. The generator's upfront cost is relatively small (US$12 000) and the probes cost approximately US$200 each, with an average of 1–1.3 probes used per case [13].

Technically, the EHL probe should be held approximately 1 mm from the stone to allow for maximal effect and at least 2–5 mm from the lens of the scope to prevent instrument damage [5]. The goal of treatment is to create fragments that can either be easily extracted or passed spontaneously. Attempts to create fragments smaller than 2 mm have a higher probability of mucosal injury.

Ultrasonic lithotripsy

The upper limit of sound audible to the human ear is generally regarded to be 20 kHz. Sound waves with a frequency above this threshold are referred to as ultrasound waves. The first attempted use of ultrasound waves to fragment urinary calculi was reported in 1953 by Mulvaney [14]. Since then the technology has progressed significantly and ultrasonic lithotripsy is now commonplace within clinical endourologic practice.

Ultrasound waves can be created through a number of different mediums. All currently available ultrasonic lithotriptors utilize a piezoelectric model (Figure 24.3) In these devices a current is applied, from a separate generator, to a piezoceramic plate that in turn is excited. The plate generates vibrational energy in the form of ultrasonic waves at a frequency between 23 and 25 kHz. This energy is transmitted through the hand piece to a solid or hollow probe that is placed in contact with the stone. The vibrations of the probe transmit the energy to the calculus, resulting in a drilling effect.

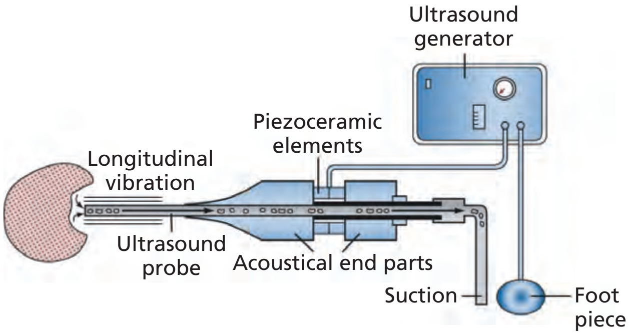

Figure 24.3 Mechanism of action of ultrasonic lithotripsy (adapted from Lingeman *et al*. [11], with permission).

Ultrasonic probes are manufactured in a variety of sizes from 2.5F to 12F. The larger probes incorporate a hollow channel through which suction is applied [the smaller probes (2.5F) are solid in design and therefore, lack suction]. The presence of this channel gives these devices a major advantage in that small stone fragments (<2 mm) can be evacuated as lithotripsy is performed. When this advantage is combined with the probe's rigidity and the inherent limitations to irrigation flow during ureterorenoscopy, it is evident why ultrasonic lithotripsy has had its greatest success during PCNL.

As the mechanism of stone fragmentation in ultrasonic lithotripsy is purely mechanical, direct contact with the stone is necessary. As pressure is used to pin the calculus between the probe and urothelium in most cases, the question of safety and the potential for urothelial perforation is of utmost concern. When Piergiovanni *et al*. studied the effect of EHL, ultrasonic, pneumatic, and laser lithotripsy on pig bladder and ureteral tissues, it was found that perforation was not possible with ultrasonic or pneumatic lithotripsy. These animals were sacrificed on days 0, 1, and 6. After histologic examination it was demonstrated that injury was limited to abrasions of the epithelium [8]. These authors concluded that ultrasound and pneumatic lithotripsy are safer than EHL and laser lithotripsy. Howards *et al*. documented similar findings of minor epithelial changes in a canine model [15].

The mechanism of stone destruction raises a concern regarding the generation of heat at the site of interaction between the stone and probe. Although there is a potential for thermal injury, it is only of concern if irrigation is interrupted, as it has been demonstrated that at an irrigation rate of 30 mL/min the change in temperature at the probe tip is minimal (1.4°C) [16].

When researchers at Long Island Jewish Medical Center compared the efficiency of four different ultrasonic lithotriptors (Wolf, Olympus, Storz, ACMI) on a plaster of Paris stone phantom model, they demonstrated that the Wolf lithotriptor was the most efficient, while the Olympus was the least efficient with incomplete fragmentation of the stone model [17]. Despite the intermanufacturer variability in efficiency, ultrasonic lithotripsy has been demonstrated to be an effective and safe means of lithotripsy.

As previously stated, a major limitation of the ultrasonic lithotriptor is its inherent rigidity. When used in conjunction with a semi-rigid ureterscope to treat ureteral calculi, a large working channel of at least 5F is needed to accommodate the smallest probe with an incorporated suction channel (4.5F). When this is not available, the solid 2.5F probe is utilized and no suction is possible. Despite these limitations, ureteroscopic success rates between 84% and 100% have been reported [18–22]. Given the rigid nature of the ultrasonic probes, which inherently limits the deflection of flexible scopes, ultrasonic lithotripsy of ureteral calculi may have its greatest utility in distal ureteral stones. This sentiment was documented in a study out of the UCLA Stone Center in which success rates of 91%, 94%, and 98% were reported in the proximal, middle, and distal ureter, respectively [23].

Ultrasonic lithotripsy has found its greatest utility in PCNL. The nephroscope's large caliber allows for the utilization of larger probes with a greater ability to evacuate stone fragments throughout the procedure. The first use of ultrasound to treat a staghorn calculus was reported in 1977 [24]. Since then many researchers have demonstrated percutaneous ultrasonic treatment of renal stones to be an effective and safe procedure with success rates of 80.4–100% [25–28].

Technically, when ultrasonic lithotripsy is applied, the stone should be trapped between the probe and the urothelium. Pressure is needed to maintain this relationship, but care should be taken to avoid excessive pressure as perforation is possible, especially in the thin-walled renal pelvis or ureter. Multiple short-duration applications of the ultrasonic energy to the stone results in fragmentation. Longer durations of activity provide shorter treatment times but carry the potential to generate a thermal injury and may lead to diminished vision. In addition to the aforementioned advantages of ultrasonic lithotripsy, it is relatively inexpensive. The generator costs approximately US$15 000 and there are no disposable components.

Pneumatic lithotripsy

Another example of a direct contact lithotriptor is ballistic lithotripsy. In this model of lithotripsy a projectile is set in motion, culminating in a jackhammer effect. Although any number of driving forces can initiate the movement of the projectile, the most notable and most widely utilized is compressed air. Using this model the Swiss Lithoclast has been found to be a very effective means of intracorporeal lithotripsy.

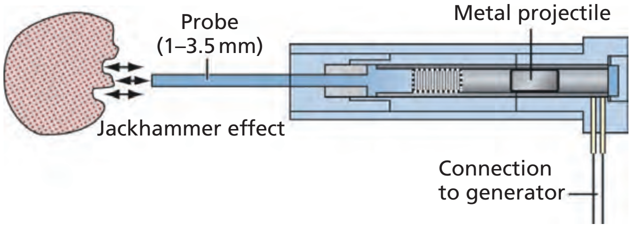

Figure 24.4 Mechanism of action of pneumatic lithotripsy (adapted from Lingeman *et al*. [11], with permission).

Developed in the early 1990s in Switzerland, the Swiss Lithoclast uses compressed air to propel a metal projectile against the head of a solid metal probe at a pressure of 3 atm and a rate of 12 Hz (Figure 24.4). Under close visual guidance, the tip of the metal probe is placed into direct contact with the calculus and repetitive impacts result in stone fragmentation. Since its first clinical use in 1991 [29], the Swiss Lithoclast has been extensively studied. Currently, probes are available in sizes ranging from 0.8 to 2.5 mm and a flexible nickel–titanium (nitinol) probe has been developed to facilitate its use in flexible endoscopy [30].

As in ultrasonic lithotripsy, the mechanism of action in pneumatic lithotripsy raises concern over the potential for collecting system injury, specifically perforation. As previously noted, when the effects of EHL, ultrasonic, pneumatic, and laser lithotripsy were evaluated on pig bladder and ureteral tissues it was determined that perforation did not occur with ultrasonic or pneumatic lithotripsy. On histologic examination, the lithoclast resulted in only partial abrasion of the epithelium and edema of deeper layers [8]. Additional animal studies have further documented the safety of the Swiss Lithoclast; notably Santa-Cruz *et al*. demonstrated no ureteral perforation following 6 min of continuous, direct contact activation in a pig model [31].

One of the limitations of pneumatic over ultrasonic lithotripsy is the solid design of the probe, and therefore the lack of a suction channel. The development of a suction channel through which pneumatic lithotripsy is commenced and suction is applied alleviated this concern. The Lithovac is available in several different widths (1.6, 3.5, and 4 mm) and lengths, and facilitates the evacuation of fragments less than 2 mm in size during lithotripsy. Fragments as large as 3.5 mm can be evacuated when the Lithoclast is removed from the channel [32]. In addition, the application of suction during pneumatic lithotripsy can counteract another major disadvantage of direct contact lithotripsy, retropulsion of stone fragments [33]. In the absence of suction, stone migration occurs in approximately 7.3% cases [11].

Pneumatic lithotripsy results in successful stone fragmentation in 73–100% of cases [9, 20, 33–37]. Its successful utilization depends upon the ability to pin a calculus between the urothelium and the tip of the probe. This is understandably more difficult within the confines of the ureter and therefore the utility of pneumatic lithotripsy is best realized during cystolitholapaxy and PCNL, especially during the treatment of large stone burden or exceedingly hard stone compositions [38, 39]. The rigid nature of the probes also limits the ability to use the Swiss Lithoclast with ureteroscopy. To counteract these limitations, the flexible nitinol probe was manufactured. Despite the added ability to use the Lithoclast with a flexible ureteroscope, a significant decrease in tip displacement and velocity, and therefore effectiveness, is noted as the scope is deflected [40].

Technically, the use of pneumatic lithotripsy is facilitated by the use of a nondeflected working channel. Direct vision should always be employed to ensure safety as well as to facilitate adequate fixation of the calculus against the urothelium. In an *in vitro* biomodel the use of a larger probe (1.6 vs 0.8 mm) resulted in higher efficacy. When the smaller probe was used, however, a slower rate of impact (6 vs 12 Hz) was found to be more effective [41].

Pneumatic lithotripsy is somewhat more costly than EHL and ultrasonic lithotripsy as the generator costs approximately US$30 000, but there are no disposable components as each probe, costing US$150, is reusable.

Combined ultrasonic and pneumatic lithotripsy

Ultrasonic lithotripsy provides the surgeon with a very effective method for stone removal. The incorporated suction channel functions to decrease the effects of stone retropulsion and further assists with the removal of fragments less than 2 mm in diameter. Unfortunately, ultrasonic lithotripsy has limitations, especially when it comes to the destruction of very dense or hard stone compositions (calcium oxalate monohydrate).

Pneumatic lithotripsy has previously been demonstrated to be a very effective endoscopic lithotriptor, especially when treating hard or very large stones [38, 39]. Unfortunately, this device results in the formation of relatively large stone fragments and the lack of a suction channel further interferes with stone removal. As previously noted, a suction device for use with the pneumatic lithotriptor (Lithovac) has been developed but has failed to gain popularity due to its propensity to clog with stone debris [32, 33].

In an attempt to combine the benefits of these two technologies, the Lithoclast Ultra was developed. This device uses a combination of ultrasonic and pneumatic lithotripsy to accomplish calculus fragmentation and evacuation. A single control unit is activated via a foot pedal and enables the surgeon to use either of the lithotriptors individually or in combination. Suction is incorporated into the ultrasonic portion of the device.

The first clinical use of the combined lithotriptor was in 2001 by Haupt *et al*. [42]. Stone fragmentation was successful in all 15 patients with renal and bladder stones. Since that time a number of *in vitro* studies have examined the efficacy of the combined lithotriptor [43–46]. Auge *et al*. compared the combined lithotriptor to both standard pneumatic and ultrasonic lithotriptors in an *in vitro* study using a rigid 27F nephroscope and a phantom stone model [44]. The combination pneumatic/ultrasonic unit was found to be significantly more efficient in completely fragmenting and clearing the stone model compared to either pneumatic or ultrasonic lithotripsy alone (7.4 vs 23.8 vs 12.9 min, respectively). In addition, the study conducted by Hofmann *et al*. found that the combination unit was able to achieve fragmentation of five different artificial stones of defined hardness and density 25–200 times faster than pneumatic or ultrasonic lithotripsy alone [47].

The clinical utility of the combined lithotriptor has been evaluated in several studies [47–49]. In the largest of these studies, 68 patients were treated for staghorn calculi over a 2-year period. Overall stone-free rate, measured by postoperative kidneys, ureters, and bladder X-ray (KUB) and ultrasound, was 89.7%, with 23.5% requiring a second-look PCNL [47]. In an additional study by Pietrow *et al*., 20 patients with symptomatic renal stones were randomized to PCNL with either the combination lithotriptor or standard ultrasonic lithotripsy. The combination device required significantly less time for complete stone clearance (21.1 vs 43.7 min), as well as a greater rate of stone clearance (39.5 vs 16.8 mm^2/min) [48]. In yet another study, 30 patients were randomly assigned to PCNL with either a standard ultrasonic lithotriptor or the combined device. The stone-free rates were similar (46% and 66.7%, respectively, $P = .26$), however the combination of ultrasonic and pneumatic lithotripsy was more efficient for harder stones [49].

Combining the pneumatic lithotriptor's ability to successfully fragment hard stones with the disintegration and suction capabilities of ultrasonic lithotripsy helps to minimize stone retropulsion, facilitate stone clearance, and decrease operative times. Further studies are required to adequately define the role of the combined ultrasonic and pneumatic lithotriptor amongst the currently available intracorporeal lithotriptors. The available literature is, however, very promising.

Laser lithotripsy

Light amplification by stimulated emission of radiation (laser) is both a mnemonic as well as a descriptive statement. Laser is a mechanism for emitting electromagnetic radiation through stimulated emission of photons. When an atom is stimulated by an external energy source, electrons become metastable and change their orbit. As this excited state decays, an emission of photons (light energy) occurs [50]. There are three differences between laser light and natural light: laser light is coherent (all photons are in phase), collimated (photons travel parallel to one another), and monochromatic (photons have the same wavelength) [50]. It is these characteristics that allow lasers to transmit high energy in a concentrated fashion.

The first functioning laser was constructed by Theodore H. Maiman in 1960 [51]. In 1966 Parsons was the first to use laser technology in urology when he experimented with the pulsed-ruby laser in canine bladders [52]. In 1968 laser technology was first utilized for lithotripsy [53]. The use of lasers was, however, limited by an excessive production of heat. The solution to the dilemma of thermal injury was the discovery of pulsed laser technology that resulted in high power density at the stone's surface with little heat dissipation [50].

Since the initial ruby laser, several lasers have been developed and implemented in intracorporeal lithotripsy. Lasers result in calculi fragmentation through several different mechanisms (see Figure 24.1). The neodynium:yttrium–aluminum–garnet (YAG) laser and Alexandrite laser function through a plasma-induced cavitation mechanism. Plasma, a gas in which a portion of the particles are ionized, is formed, and expands at the tip of the laser fiber. The rapid expansion and collapse of the resultant plasma bubble generates an acoustic shock wave that fragments the stone [54]. The holmium:YAG laser (HoL) is the only laser that is capable of fragmenting all compositions of calculi. It functions through a primary photothermal that results in stone vaporization [55, 56]. Despite the fact that the HoL is the most recently developed laser technology, it has become the most widely clinically utilized laser and is the laser on which our discussion will focus.

The holmium: YAG laser

The HoL is a solid-state laser operating at a wavelength of 2100 nm. Since its inception, HoL lithotripsy has been widely accepted as an intracorporeal lithotriptor. In fact, the most recent edition of *Campbell–Walsh Urology* states, "the holmium laser has become the mainstay of ureterorenoscopic lithotripsy" [11]. HoL fibers are available in diameters ranging from 200–1000 µm. Both the 200 µm and 365 µm fibers can be used with both semi-rigid and flexible ureteroscopes, and their flexible nature allows for preservation of flexion capabilities during ureteroscopy, a significant advantage.

The HoL is highly absorbed in water. Given that human tissues are chiefly composed of water, the energy of the HoL is absorbed superficially. In fact, the depth of tissue penetration has previously been proven to be 0.5–1.0 mm [31, 57]. This allows for safe use within the collecting system. In an *ex vivo* comparison of four different lithotriptors in a porcine ureteral model, the HoL was unable to induce perforation at a distance of 2 mm, even at very high power settings [31]. This is not to say that the HoL is unable to perforate the ureter. Several studies have found that both the EHL and HoL lithotriptors are more capable of ureteral perforation than ultrasonic and pneumatic lithotripsy. In one study, the HoL was reported to perforate the ureter after only 2 s of direct contact activation [8, 31].

Throughout the literature HoL lithotripsy has been demonstrated to be very effective, with success rates of 91–100% and stone-free rates after ureterorenoscopy of 87–100% [58–64]. Calculus location within the collecting system has been proven to affect HoL lithotripsy success. In a study of 598 stones treated with HoL lithotripsy, Sofer *et al*. evaluated patients at 6–12 weeks postoperatively and demonstrated an overall stone-free rate of 97%. When the procedures were stratified by stone location (renal, proximal ureter, middle ureter, and distal ureter), stone-free rates were 84%, 97%, 100%, and 98%, respectively [64].

The HoL is not solely used for retrograde approaches to calculi. HoL lithotripsy has been extensively used for PCNL, with success rates after a single session ranging from 61.4% to 89% [65–67]. When Malik *et al*. compared the HoL and pneumatic lithoclast in 60 patients undergoing PCNL of a single 2.5 cm stone, complication rates were similar as were the stone-free rates. Operative time, however, was significantly longer in the HoL group [68].

A group from China recently reported their experience with a novel approach to PCNL. Li *et al*. gained access to a posterior middle calyx via the 11th intercostal space and dilated their tract to 20F. The entire PCNL was then performed through this access with either an 8/9.8F semi-rigid ureteroscope or a 8.5/12.5F nephroscope. At the beginning of the procedure a 5–7F ureteral catheter was placed in a retrograde fashion to the level of the uteropelvic junction . This catheter was utilized to prevent stone migration, facilitate renal puncture, and for the instillation of forceful retrograde irrigant (normal saline) throughout the procedure. Either pneumatic or HoL lithotripsy was then employed through an average of 1.2 tracts per patient [69].

These authors reported their results from a total of 4760 minimally invasive PCNLs (MPCNLs) performed in 3610 kidneys, including 1240 staghorn calculi. An average of 1.3 procedures were performed on each kidney with an average operative time of 78 min.

Throughout the procedure stone fragments less than 0.3 cm were evacuated via the continuous instillation of irrigant through the indwelling ureteral catheter via a novel endoscopic pulsed perfusion pump. The authors utilized either a KUB or nephrostography postoperatively to assess for efficacy. At 48 h they achieved a stone-free rate of 89% with a significant complication rate of only 0.86% [69].

Li *et al*. concluded that their method of MPCNL provides a safer environment for percutaneous stone management with a lower risk of renal vessel injury. They note, however, that the long shaft of the instruments used can be quite cumbersome and a surgeon may require time to master the procedure [69].

The clear benefits of HoL lithotripsy include its ability to effectively fragment all stone compositions. In addition, the flexible nature of the laser fiber facilitates both flexible ureteroscopy and renoscopy (both antegrade and retrograde). The superficial penetration of the HoL laser provides it with a high margin of safety as long as care is taken to keep the fiber at least 1 mm from the urothelium. In addition, the lack of photoacoustic effects has resulted in the safe use of HoL lithotripsy in patients receiving anticoagulation therapy [70].

The disadvantages of HoL lithotripsy lie within its propensity to perforate the urothelium if activated within close proximity to the wall of the collecting system. In addition, the high initial cost of the HoL and its fibers is a deterrent to some institutions. The versatility of the HoL to treat multiple urologic diseases, including transitional cell carcinoma [71, 72], ureteral strictures [73–75], and benign prostatic hyperplasia [76–78], as well as nonurologic conditions [79, 80], however, helps to counteract the initial costs. As with other lithotriptors, stone retropulsion is also a concern in laser lithotripsy. In an *in vitro* model the 365 μm and 550 μm fibers were associated with the greatest degree of retropulsion, and the 200 μm fiber with the least [81]. Interestingly, HoL lithotripsy of uric acid stones produces cyanide gas. Despite the theoretical side effects of this, no significant cyanide toxicities have occurred as a result of HoL lithotripsy [82].

Technically, the HoL fiber should be kept at least 2 mm beyond the end of the endoscope to avoid damage to the lens system. We consider a systematic painting motion to represent the ideal use of the HoL. This process of lithotripsy allows for vaporization of the stone and avoids the formation of large fragments. When performing HoL lithotripsy it is important to remain vigilant in monitoring stone position to avoid ureteral injury. Care should be taken not to tunnel through a calculus as perforation through the opposite side may result in urothelial injury. In addition, care should be taken to avoid wires, baskets, etc. during laser lithotripsy as the HoL is capable of cutting through metal [83].

Conclusions

The most important determinant of which intracorporeal lithotriptor will prove most useful remains the specifics of the clinical situation. When treating stones in a retrograde fashion, i.e. ureterorenoscopy, the flexibility of the EHL and HoL lithotriptors may prove most beneficial. The HoL, in particular, has proven to be an extraordinarily versatile weapon within our arsenal of treatment modalities for urolithiasis.

When the larger stone burdens are encountered during PCNL, the mechanical lithotriptors, i.e. ultrasonic, pneumatic, and combination lithotriptors, may prove to be a superior choice. Their efficiency allows an experienced surgeon to treat large stone burdens with optimal operative times and low complication rates.

At our institution we consider a complete PCNL to be one in which both rigid and flexible renoscopy are employed to truly render the patient as stone free as clinically possible. We have found the combination of ultrasonic and pneumatic lithotripsy to be superior and therefore we employ the Lithoclast Ultra. Once the largest stone burden has been adequately eliminated, the rigid renoscope is exchanged for a flexible cystoscope through which the HoL is utilized to fully evaluate all calyces and fragment any residual stone fragments. Using this algorithm, patients have the greatest chance of being rendered stone free on follow-up imaging.

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PART 6 Other Uses of Nephrostomy Access

CHAPTER 25

Percutaneous Treatment of Calyceal Diverticula, Infundibular Stenosis, and Simple Renal Cysts

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Introduction

Since its introduction in 1976, percutaneous nephrolithotomy (PCNL) has become an accepted treatment for urolithiasis [1]. Within one decade, PCNL evolved from a highly skilled undertaking performed by a handful of surgeons to a routine procedure performed by most urologists. Current indications for PCNL are large stone burdens, lower pole calculi, cystine stone disease, abnormal renal anatomy, and stones not amenable to ureteroscopy (URS) or shock-wave lithotripsy (SWL) [2]. Certain advantages of PCNL have been noted over open nephrolithotomy and SWL, including superior stone clearance, limited convalescence, and cost-effectiveness [3]. Although major complications are possible, analysis has demonstrated overall safety and effectiveness of this technique for complex calculi [4]. When complications occur at the time of PCNL they are often a result of obtaining percutaneous access, but can also result from the technique of stone removal and include hemorrhage, arteriovenous fistula, sepsis, hydrothorax, colocutaneous fistula, injury to surrounding viscera, ureteral avulsion, hypothermia, volume overload, electrolyte imbalance, myocardial infarction, pulmonary embolism, and death [5–7]. Notwithstanding the potential immediate complications, PCNL is considered to be without major long-term effects [8].

Due to the low complication profile and patient morbidity the limits of percutaneous surgery have been expanded from the realm of stone disease to the treatment of not only other benign conditions, but also renal malignancy. Furthermore, with advancements in imaging, surgical equipment, and technique, the success rate of percutaneous surgery has improved without compromising patient safety.

In this chapter we will review the role of percutaneous surgery in the treatment of three benign conditions: calyceal diverticula, infundibular stenosis with hydrocalyx, and renal cyst disease.

Calyceal diverticula

A calyceal diverticulum is a congenital smooth walled, nonsecretory urothelium-lined cavity within the renal parenchyma that communicates with the calyceal fornix through a diverticular neck. Urine is received by the diverticulum through passive retrograde filling from the adjacent collecting system, which can include the renal pelvis. Failure of small ureteral buds to degenerate is thought to be the origin of the diverticular variation. Calyceal diverticula are uncommon and have been noted in 0.21–0.6% of patients undergoing renal imaging [9–12], with bilateral occurrences observed in only 3% of patients with diverticula [13]. Calculi occur in 9.5–50% of diverticula. Although many of these cavities are asymptomatic, they can be associated with pain, hematuria, recurrent urinary tract infections (UTIs), and even damage to surrounding parenchyma [10, 12, 14, 15]. Furthermore, complete obstruction of the diverticular neck can be associated with sepsis, abscess formation, or hypertension [16].

The etiology of calyceal diverticular calculi is controversial, with both urinary stasis and underlying metabolic abnormalities implicated as factors [17–20]. It has

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been suggested that particle retention secondary to urinary stasis, especially in the setting of a diverticulum, could be the cause of stone formation [20]. Liatsikos *et al*. further suggested stasis as a cause of diverticular calculi formation as they noted a low incidence of metabolic abnormalities in their cohort (25% in the calyceal diverticulum cohort vs 77.3% in other stone formers) [18]. However, other studies have noted metabolic derangements in 50–100% of patients with diverticular stone disease [17, 21]. More recently, both metabolic and stasis factors have been implicated [19]. Matlaga *et al*. compared the 24-h urine studies of 29 patients with calyceal diverticula to 245 calcium oxalate stone formers and 162 normal patients. They found that the urinary stone risk parameters of patients with calyceal diverticular stones were similar to those of the calcium oxalate stone-forming group. Furthermore, when compared to the normal cohort, the calyceal diverticular and calcium oxalate stone formers were significantly more hypercalciuric and their urine was significantly more supersaturated with calcium oxalate. Interestingly, the urine aspirated from the diverticulum of three patients in Matlaga *et al*.'s series demonstrated a significantly lower supersaturate of calcium oxalate compared to urine obtained from the renal pelvis of the same patient. The authors hypothesized that although these patients have baseline metabolic derangements, the urinary stasis in the diverticulum allows for incorporation of ions into a stone nidus, thus propagating stone formation and lowering local calcium oxalate supersaturation.

Diagnosis

The differential diagnosis for a calyceal diverticulum includes renal cyst, malignancy, solitary abscess, and most commonly hydrocalycosis secondary to infundibular stenosis. In geographic locations where tuberculosis is prevalent, the differential diagnosis of cortical cavitation secondary to renal tuberculosis should be considered, as the radiologic appearances of these two conditions may be similar [16]. Those patients who have an incidentally discovered asymptomatic calyceal diverticulum do not require treatment. However, for patients presenting with pain, recurrent UTI, hematuria, symptomatic calculi, or progressive renal damage, treatment should be undertaken.

The work-up for a calculus in a calyceal diverticulum includes urinalysis, complete blood count, basic metabolic panel, and imaging of the abdomen. The urine study should include both microscopy and a urine dipstick test for leukocytes, erythrocytes, protein, nitrites, and pH.

Initial imaging studies depend on the physician's practice preference and can be a renal ultrasound, plain abdominal X-ray [kidneys, ureters, and bladder (KUB)], or noncontrast computed tomography (CT) scan. Renal ultrasound will accurately diagnose a calyceal diverticulum in 80% of cases [22], with the classic ultrasound finding of milk of calcium [23]. When echogenic material is present in the affected kidney, the patient is scanned in different positions to demonstrate gravitational changes of the content, which is diagnostic of a calyceal diverticulum. KUB can also diagnose a calyceal diverticulum if milk of calcium is present. The milk of calcium will appear as a meniscus-like, half-moon-shaped calcification. Calyceal diverticula are often easily identified on noncontrast CT as a dilated outpouching from the collecting system containing a stone.

Once the diagnosis of a calyceal diverticulum is suspected, imaging of the collecting system should be performed to assess location of the diverticulum and communication with other elements of the kidney. With an intravenous pyelogram (IVP) or CT urogram, most calyceal diverticula will opacify if they have significant communication with the collecting system. The opacification will occur later in the examination since the diverticulum is filled in a retrograde fashion from the calyx or renal pelvis and thus delayed images are necessary [24]. A retrograde pyelogram can be helpful in determining where the neck of the diverticulum is located (Figure 25.1). If the neck or infundibulum is obstructed, the diverticulum will not opacify. The presence of an obstructed infundibulum can dictate how access to the calyceal diverticulum is achieved.

Treatment

Patients with calyceal diverticula can present a treatment challenge. Historically, these patients were treated by open surgical closure of the infundibulum, marsupialization and fulguration of the diverticular cavity, or partial nephrectomy. With technologic advances, the treatment of calyceal diverticula has become less invasive. Current minimally invasive treatment for patients with symptomatic calyceal diverticula includes SWL [25–27], URS [28–31], PCNL [24, 24, 28, 32–38], and laparoscopy [39, 40–44].

SWL for the treatment of calyceal diverticula is controversial. Although at short-term follow-up SWL can provide symptomatic pain relief in 36–70% of patients, stone-free rates are low, ranging from 4% to 20% [25, 26]. Jones *et al*. have found that with longer observation, patients initially rendered symptom free with SWL will subsequently become symptomatic and require retreatment [25]. The highest stone-free rate reported for SWL of calyceal diverticular calculi remains suboptimal at 58% [27]. Thus, SWL is rarely considered as monotherapy for calyceal diverticula as most investigators agree that to prevent stone recurrence, eradication of the diverticulum should accompany stone removal, a goal that is rarely achieved with SWL [45, 46].

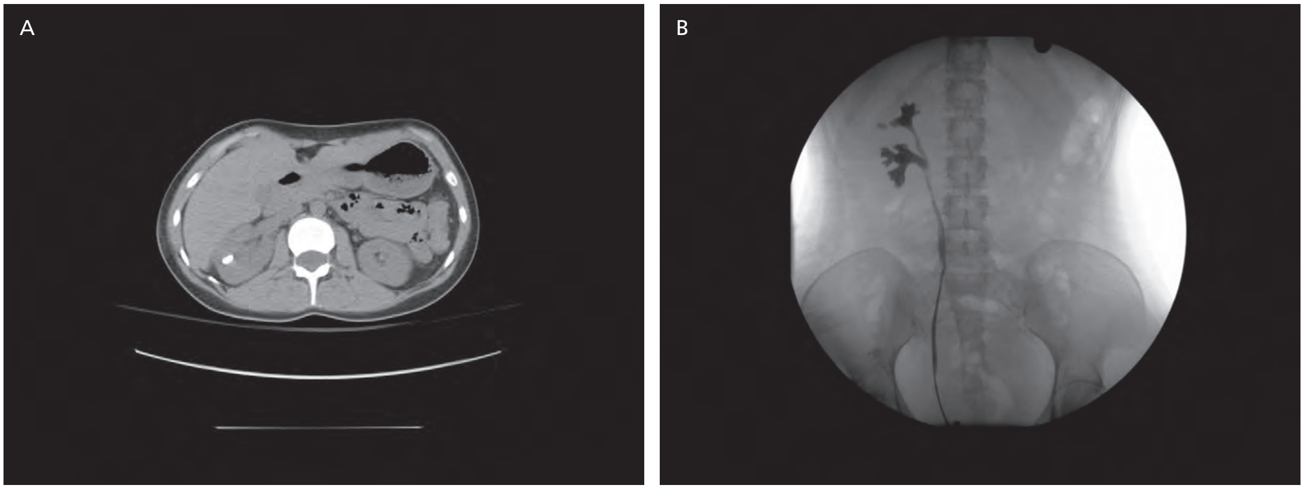

Figure 25.1 (A) Symptomatic calyceal diverticulum containing stone material in right kidney noted on CT scan of the abdomen and pelvis. (B) Retrograde pyelogram confirms location of the neck of the infundibulum to be originating from an upper pole calyx.

An advantage of URS over SWL is that while both are minimally invasive, URS allows for simultaneous ablation of the diverticular cavity. Retrograde URS is a reasonable option for certain patients with a diverticulum in the upper or middle portions of the kidney when the stone burden is small and the diverticular neck is short and easily accessible [45, 47]. Stone-free rates for URS range from 19% to 73%, but diverticular obliteration is as low as 18%; furthermore, a significant number of patients demonstrate residual symptoms and require retreatment [31, 32, 46]. Identification of the diverticular neck can be difficult with a retrograde approach and may account for the lengthy operative times (1.25–4 h) reported in some URS series [31, 47]. Furthermore, multiple treatments can be necessary to render the patient stone free and to completely ablate the cavity.

Laparoscopic management of calyceal diverticula has been described, but the indications for such an approach are limited. It has been suggested that anterior diverticula, especially if there is a thin layer of parenchyma overlying a large cavity, are suitable for laparoscopy [39, 40]. However, the laparoscopic approach is more invasive than PCNL with lengthy operative times (up to 2.5 h) even in experienced hands [40], thus limiting its widespread application. In general, laparoscopic management is reserved for diverticula that are large and extremely anterior or in ectopic kidneys where a percutaneous approach will be hampered.

Percutaneous treatment of calyceal diverticular calculi achieves high stone-free (87.5–100%) and obliteration rates of the diverticular cavity (76–100%) [24, 25, 33, 34, 36–38]. Over 90% of patients report symptomatic relief with percutaneous treatment [25, 28, 33–36] and long-term studies have demonstrated these results to be durable [36]. In most cases percutaneous access is directly into the calyceal diverticulum to allow use of a rigid nephroscope [45]. Direct puncture can be difficult if the cavity is small or if the calyceal diverticulum is located in the upper pole of the kidney. If direct puncture into the calyx fails, a neighboring calyx can be punctured and the diverticulum entered indirectly by perforating the wall of the diverticulum or by entering in a retrograde fashion, through the diverticular neck [48]. However, the indirect access technique is associated with inferior results and thus should be reserved as a secondary measure [49].

Biplanar fluoroscopy is the imaging modality most commonly used for percutaneous access when subsequent PCNL is planned [50]; this technique requires a radio-opaque target to aim at. Kim *et al*. have described a single-stage technique where percutaneous access is directed straight onto the stone [38]. If the targeted diverticular calculi are not visible with fluoroscopic imaging, contrast can be instilled into the diverticular cavity via a ureteral catheter placed in a retrograde fashion [36]. However, if the diverticular communication with the intrarenal collecting system is attenuated, the diverticulum may not readily fill with contrast. In such circumstances, ultrasound guidance can be utilized [51]. Unfortunately, it is difficult to monitor the guidewire manipulation with ultrasound imaging. Matlaga *et al*. have described CT- or ultrasound-guided pre-PCNL opacification of the calyceal diverticulum as an alternative approach [24]. Opacification of the diverticulum by interventional radiology provides the necessary target for percutaneous access in the operating room.

Once access is obtained into the diverticular cavity, stone removal is performed. It is imperative the patient is rendered stone free. Kim *et al*. noted successful obliteration of the diverticular cavity was closely associated with rendering the patient stone free, and that successful obliteration of diverticula ranging from 5 to 44 mm in diameter was possible when the cavity was completely cleared of stone material; however, residual fragments increased the risk of incomplete diverticular resolution [38]. After all stone material is extracted, the urothelium should be inspected in an effort to identify a flattened renal papilla, the presence of which indicates an obstructed hydrocalyx rather than a calyceal diverticulum.

Once the cavity is confirmed to be a true diverticulum, treatment can include creating a large communication to the collecting system to promote drainage and prevent urinary stasis. When the infundibular connection to the renal collecting system can be found, dilation of this communication can be performed and the area stented with a nephrostomy tube [25, 34, 37]. If the infundibular connection cannot be found or traversed with a wire, some have advocated creation of a neoinfundibulum into the calyx or the renal pelvis [32, 35]. Both techniques require the placement of a nephrostomy tube for a prolonged period to ensure the channel will remain open. Furthermore, dilation of the infundibulum and creation of a neoinfundibulum have the potential to create significant bleeding. Neoinfundibulotomy should not be performed when the diverticulum is located anteriorly and normal parenchyma is traversed and dilated to form a connection to the collecting system [35].

Another treatment strategy is to fulgurate the diverticulum. Although the need for cavity ablation or destruction is a controversial issue [31], since the calyceal diverticulum is lined by a nonsecretory endothelium, most authors advocate fulguration at the time of PCNL [45]. Hulbert *et al*., however, suggested that trauma to the wall of the diverticulum caused by the percutaneous dilation process is sufficient to ablate the diverticular lumen [33]. Conversely, others have reported that dilation or incision of the diverticular neck without fulguration results in complete ablation of the diverticulum in only 30% of cases [52], as opposed to the 76–100% ablation rate when fulguration is performed [25, 34, 36, 53]. If fulguration is to be performed, the infundibulum of the diverticulum should not be dilated to maximize the chance of diverticular obliteration. Diverticular fulguration can be performed with [36] or without [38] ureteral catheterization utilizing a direct percutaneous access technique. Monga et *al*. performed fulguration of the calyceal diverticulum lining without any attempt at cannulation of the infundibular communication [36]. All patients were left with a ureteral stent for 2–4 weeks and the nephrostomy tube was removed at 24–48 h. The authors reported a 100% diverticular ablation rate and all patients were symptom free at 38 months follow-up. Kim *et al*. also presented their series of percutaneous diverticular ablation without identification of the infundibulum; however, ureteral catheters were not placed in this series and 20 of 21 patients were sent home tubeless on postoperative day 1 [38]. Operative times for this series were less than 60 min. At 3-months follow-up, all diverticula had decreased in size and 87.5% had completely resolved.

Technique

If retrograde instillation of contrast is not necessary because the diverticulum is easily identified from its stone contents, a single-stage procedure is performed. In a single-stage PCNL technique, patients are placed in the prone position without an external ureteral catheter. A C-arm is used to visualize the diverticular calculi. When possible a direct infracostal puncture is performed using an 18G diamond-tipped needle and a biplanar fluoroscopic triangulation technique [45]. When access is achieved, a 0.035-inch J-tipped movable core guidewire is coiled inside the diverticular cavity, taking care to avoid wall perforation with the stiffer portion of the wire. The main advantage of the movable core J-wire is that the flexible distal end of the wire can be adapted to the size of the diverticulum, while the wire proximal to the moved core remains stiff enough to function as the working wire. With the J-wire in place, an 8/10F coaxial dilator is passed over the J-wire in a sequential fashion. The 8F dilator is removed and a second 0.035-inch J-tipped movable core wire is coiled inside the diverticulum and used as the safety wire. The tract is balloon dilated over the working wire. Special attention is given to the placement of the balloon dilator and the wires to prevent any trauma to or perforation of the back wall of the diverticulum. A 30F Amplatz sheath is then passed over the balloon dilator under fluoroscopic guidance. The balloon dilator has a taper on the distal end that precludes placement of the sheath directly into the diverticular space unless the diverticulum is large. Next, an offset 24F rigid nephroscope is placed inside the access sheath using normal saline irrigant. An 11F alligator forceps is used to manually dilate the part of the tract immediately adjacent to the diverticulum, allowing for advancement of the scope and subsequently the sheath into the diverticular lumen (see Video 25.1).

Once the offset nephroscope is gently guided into the diverticular cavity, ultrasonic lithotripsy or grasping forceps are used to remove the stone burden. After removal of all stone material and confirmation that a renal papillae is not present, the irrigant is switched to 1.5% glycine and a resectoscope with a rollerball electrode is used to fulgurate the diverticular lining (see Video 25.2). The infundibular communication is neither assessed nor dilated. An 18F red rubber catheter or an

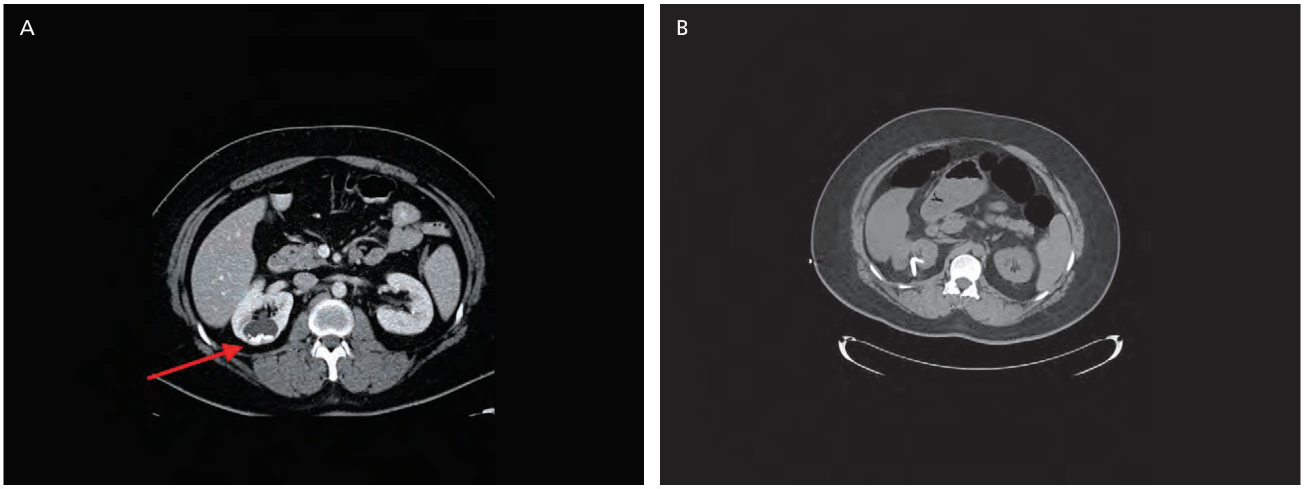

Figure 25.2 (A) Large calyceal diverticulum located in the right kidney containing stone debris (arrow). (B) Post percutaneous removal of stone and ablation of the cavity; note the 10F Cope loop nephrostomy tube in place.

8.5F Cope loop catheter is placed in the cavity at the conclusion of the procedure (Figure 25.2). The Cope loop is only used for calyceal diverticula that are large enough to house the entire loop. Proper placement of the nephrostomy tube is confirmed by contrast instillation under fluoroscopy. If the diverticulum is small, the red rubber catheter acts as a perinephric drain, as it usually becomes dislodged from the diverticular cavity.

For patients in whom the stone cannot be visualized fluoroscopically, either because it is too small or is radiolucent, the direct puncture technique cannot be performed unless the diverticulum is first opacified. In such cases, a retrograde pyelogram is first performed via a ureteral catheter. If the diverticulum does not readily opacify due to a narrow infundibulum, percutaneous opacification with either CT or ultrasound guidance is performed. The patient is transported to the radiology suite, CT or ultrasound is used to identify the diverticulum and, a puncture site overlying the posterior aspect of the kidney is selected. Local anesthesia is injected and a 20G spinal needle is manipulated under radiographic guidance into the calyceal diverticulum. Iodinated contrast is gently instilled until resistance is encountered, and KUB imaging is performed to confirm opacification of the diverticulum. Care must be taken not to inadvertently overfill the diverticular cavity by instilling contrast under too great a pressure, as extravasation may occur, making subsequent fluoroscopic targeting difficult. The patient is then transported directly to the operating room. Renal access and PCNL are performed as outlined above. It is imperative that little time elapses from the injection of contrast to the initiation of the procedure as too long a delay may permit the absorption of the contrast and the loss of the target.

Potential complications

The general complications associated with percutaneous access apply to percutaneous treatment of calyceal diverticula: hemorrhage, retroperitoneal extravasation, pneumothorax, hemothorax, and adjacent organ injury (see Chapters 30–32). However, some unique complications bear special mention. If ablation of the diverticular cavity is to be performed without infundibular dilation, it is imperative that infundibular stenosis is ruled out by lack of papillae visualization. If infundibular stenosis is misdiagnosed as a calyceal diverticulum and fulguration of a dilated calyx with functioning papillae is performed, urinoma with fistula formation can occur. Since only a targeted stone is generally treated in the case of a calyceal diverticulum, we generally make every effort to place our access site infracostal, thus substantially decreasing the risk of pleural injury and subsequent hydrothorax. Another unique theoretical complication is hyponatremia. Ablation of the calyceal diverticular cavity should be performed quickly. If the access sheath is not properly positioned or an extensive amount of time is spent ablating the cavity, absorption of the water irrigant necessary for cauterization can potentially occur.

In most instances it is not possible to pass a guidewire into the main renal collecting system from the diverticulum. With the access wire only coiled in the diverticulum, loss of access is a realistic complication. If serial dilation is performed, a false passage can be created through repetitive insertion and removal of dilators over a poorly secured access wire. If balloon dilation is performed, care must be taken not to advance the dilator too far into the diverticulum and cause posterior wall perforation leading to hemorrhage. For small diverticula, we suggest just placing the tip of the balloon dilator into the diverticulum so that the access sheath is just outside the diverticulum. The remainder of the tract is then manually dilated under direct vision using grasping forceps. Once the scope is securely inside the diverticulum, the access sheath can then be advanced over the nephroscope.

Outcomes

Percutaneous treatment of calyceal diverticular calculi achieves a stone-free rate ranging from 87.5% to 100% and cavity obliteration rates of 76–100% [24, 25, 33, 34, 36–38]. Recently, two techniques for the treatment of calyceal diverticula were recently compared: an older technique where the communication between the diverticulum and the collecting system is identified and dilated, and a newer technique where the cavity is just ablated [54]. The old technique was utilized in 28 patients and the new technique of diverticular fulguration in 57 patients. The age and gender distribution of both cohorts was similar. Of the 45 patients with location of the diverticula documented, 21 (46.7%) were upper pole, 18 (40%) mid pole, and six (13.3%) lower pole. Mean diverticular diameter was 15.8 mm (range 5–44 mm). Mean operative time was longer for the old technique cohort at 96.4 min (range 30–210 min) compared to 67.3 min (30–150 min) in the new treatment group. This difference was attributed to the new technique not requiring cystoscopy and external stent placement. A postoperative noncontrast CT scan was performed on 74 (87.1%) patients, and of these 66 (89.2%) were stone free after the initial procedure. Compared to the old technique, the new technique had a higher initial stone-free rate (94.2% vs 77.3%). Overall, final stone-free rate after primary and secondary PCNL for the entire cohort was 97.5% (78 of 80). Mean length of hospitalization was longer in the old technique cohort compared to the new (2.32 vs 1.12 days). Postoperative complications occurred in eight patients (9.4%). Overall, blood transfusions were required in three patients and two patients experienced a pulmonary complication.

There were 26 real units with the new ablation technique that had follow-up IVP at 3 months. The diverticulum was only visible on follow-up imaging in seven patients, and in four of these a decrease in size was noted, while there was no comment on size by the radiologist in the other three. Over the follow-up period, no patients experienced recurrent stone events in the area of the calyceal diverticulum. In summary, when the old infundibular dilation technique was compared to the new percutaneous diverticulum dilation technique, we noted a shorter hospitalization time and higher stone-free status with with the latter.

Post-treatment evaluation

All retrieved stone material should be sent for stone analysis to assess stone composition. Abdominal imaging should be obtained to assess stone-free status after surgical intervention. We prefer a noncontrast CT scan on postoperative day 1 prior to removal of the nephrostomy tube. To assess resolution of the calyceal diverticulum imaging of the collecting system should be performed at 3 months postoperatively either with an IVP or CT urogram.

Metabolic evaluation should also be performed 4–6 weeks after surgery or prior to surgical intervention. The current literature supports metabolic evaluation for patients with calculi containing calyceal diverticula. All patients with a calyceal diverticulum evaluated in one study had at least one metabolic abnormality, including hypercalciuria, hyperuricosuria, hypocitraturia, and hyperoxaluria [21]. The most common abnormality noted was low urine volume. Matlaga *et al*. noted that patients with calyceal diverticula had similar stone risk parameters as a cohort of patients with calcium oxalate stones without calyceal diverticula [24]. Both the calyceal diverticula and the calcium oxalate stone cohorts had significantly higher stone risk parameters when compared to a group of normal patients. Based on these studies, we perform metabolic evaluation for all patients treated for a symptomatic calyceal diverticulum.

Infundibular stenosis

Infundibular stenosis is defined by a dilated calyx with or without stone, draining through a narrowed infundibulum into a nondistended renal pelvis. It can be caused by extrinsic compression by malignancy or retroperitoneal fibrosis. Infundibular stenosis can also be caused by intrinsic narrowing from tuberculosis, chronic stones, infection, or scarring secondary to iatrogenic injury [55]. A rare cause of infundibular stenosis is a crossing segmental artery, which generally affects an upper pole calyx and is known as Fraley's syndrome [56]. Occasionally, an infundibular stenosis will be so severe that the infundibulum becomes completely occluded and there is no communication between the calyx and renal pelvis, which is termed an excluded calyx. Since the infundibular stenosis is so rarely encountered, the true incidence of the disorder is unknown.

Genitourinary tuberculosis (TB), although rare, deserves special discussion as it is the most common cause of infection-induced infundibular stenosis. Most patients with infundibular stenosis secondary to TB are asymptomatic, but they can present with microhematuria, painless frequency, recurrent cystitis, and the hallmark diagnostic sign of sterile pyuria [57]. Up to 20% of patients will present with renal calcifications and focal

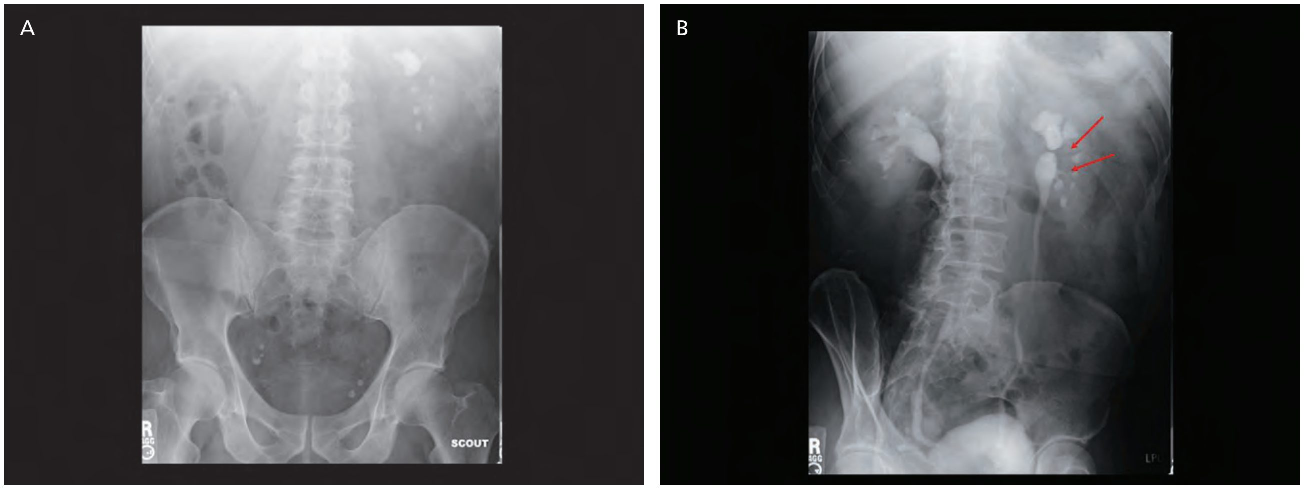

Figure 25.3 (A) Plain abdominal X-ray of the abdomen and pelvis demonstrating multiple calyceal stones in the left kidney. (B) Excretory urogram demonstrates stenosis of multiple infundibuli leading to the stone-containing calyces (arrows).

TB involvement [58]. Approximately 90% of patients with renal TB will have a positive tuberculin skin test, denoting prior inhalation exposure, but not active disease. Definitive diagnosis is made with serial, at least three, early morning urine collections for acid-fast smear and culture. Polymerase chain reaction tests can also be used and are highly sensitive and specific, with results available within hours as opposed to the weeks necessary for culture results. Once the diagnosis of infundibular stenosis secondary to TB is made, initial management with anti-TB chemotherapy should be performed. If the stenosis does not respond after 4–6 weeks of appropriate chemotherapy and remains symptomatic, then surgical intervention should be instituted. Dilation of the stenosis is rarely successful and therefore partial nephrectomy versus complete nephrectomy should be considered [57, 58].

Diagnosis

Similar to calyceal diverticulum, infundibular stenosis can be entirely asymptomatic and in many instances is discovered incidentally. Acquired infundibular stenosis, although generally asymptomatic, has been reported to lead to progressive renal failure, and some physicians advocate surgical correction [59]. Symptomatic patients with infundibular stenosis most commonly present with flank pain. Other presenting symptoms include hematuria and recurrent UTIs [55]. Stone material may or may not be present in the hydrocalyx giving rise to the above symptoms. The differential diagnosis of infundibular stenosis includes calyceal diverticulum and renal cyst.

The diagnosis of infundibular stenosis is suggested radiographically, but can only truly be made by endoscopic visualization of a papilla in the dilated hydrocalyx. With contrast imaging either via CT urogram or excretory urogram, infundibular stenosis is demonstrated by a dilated cystic outpouching of collecting system within the kidney that may or may not communicate with the renal pelvis (Figure 25.3). If the original imaging suggests the presence of a crossing segmental renal artery, an arteriogram or CT angiogram should be obtained before any endourologic surgical removal to prevent potential complications as formal surgical repair may be necessary [60, 61].

Treatment

The two indications to treat an infundibular stenosis are to relieve obstruction of the dilated calyx or to permit access to a retained stone within the calyx. There are four possible approaches to the treatment of infundibular stenosis: laparoscopic, retrograde ureteroscopic, percutaneous direct, and percutaneous indirect.

In general, hydrocalyx with functioning draining parenchyma should not be approached laparoscopically [62]. Wolf reported his experience with two cases of infundibular stenosis treated laparoscopically [62]. One case was misdiagnosed as a calyceal diverticulum and resulted in a postoperative urinoma; the other cases was successfully treated. Successful laparoscopic treatment requires proper technique and appropriate patient selection. The ideal candidate for laparoscopic treatment is a poorly functioning renal segment that is anteriorly located. If laparoscopic treatment of infundibular stenosis is performed, the renal parenchyma should be thoroughly fulgurated to ensure no functional tissue remains.

Ureteroscopic treatment of infundibular stenosis is also possible [61, 63] and its success relies on the use of the holmium:YAG laser. If the infundibulum can be seen and cannulated with a wire ureteroscopically, it is then opened using the holmium laser. If bleeding is minimal, then the infundibulum is further dilated using a balloon over the wire previously placed fluoroscopically. The dilated infundibulum is then stented for 4–6 weeks to allow adequate healing. Most reports on ureteroscopic treatment have been limited to case studies and long-term follow-up is lacking; however, for appropriately selected patients, it is an appropriate treatment alternative.

Percutaneous treatment can be performed with direct puncture into the hydrocalyx or through indirect puncture into an adjacent calyx. Either technique is acceptable. Determination of which technique to use is based on the location of the affected calyx and adjacent anatomy. In general, the approach for treating infundibular stenosis through the direct approach is very similar to that for the treatment of a calyceal diverticulum. A retrograde ureteral catheter is placed to opacify the collecting system and the hydrocalyx. If the calyx is completely excluded and no stone material is present to aim for fluoroscopically, then ultrasound- or CT-guided access is necessary if a direct approach is to be utilized.

Technique

Percutaneous access to the affected renal segment is obtained using a similar technique to that already described for a calyceal diverticulum. Retrograde instillation of contrast outlines the calyx in question. After the hydrocalyx is accessed, if the initial guidewire does not easily cross the infundibulum into the main collecting system, then the wire is coiled in the hydrocalyx in a similar fashion to a calyceal diverticulum. Once the access sheath is positioned in the calyx after balloon dilation of the percutaneous tract, the calyx is inspected with a rigid or flexible nephroscope to identify the papilla and the infundibulum. If the infundibulum is not easily identified, then retrograde instillation of methylene blue or indigo carmine via the external ureteral catheter may be helpful. In the case of an excluded calyx where an infundibulum will not be identified, some authors advocate the retrograde advancement of a wire through the external ureteral catheter fluoroscopically while the surgeon observes the calyx through the nephroscope [55]. Movement produced by the wire allows for identification of the main collecting system and may permit successful cut down through the stenosed segment to the wire.

Once the infundibulum is identified, a hydrophilic wire is advanced across it into the main collecting system. The infundibulum can then either be balloon (6 mm × 4 cm) dilated or incised with a holmium laser or cold knife. If incision is to be performed, the area should be inspected for any obvious underlying pulsations and then cuts made at the superior and inferior aspects to limit blood loss [64, 65]. A single deep cut is to be avoided as this may result in unnecessary bleeding. Incision can then be augmented with balloon dilation performed under fluoroscopic guidance.

After dilation of the infundibulum, the hydrocalyx should be drained. Placement of a ureteral stent across the dilated infundibulum, with proximal coil in the hydrocalyx and distal coil in the bladder, is one option. A standard double-J stent can be used. Others have suggested that placement of two standard stents is optimal [64]. If placement of a stent is to be performed, we prefer an endopyelotomy stent with a larger proximal diameter and quick taper to a standard 7F distally. Another option for drainage is to place the nephrostomy tube across the infundibulum with coil in the renal pelvis. No study has demonstrated that eventual infundibular patency is affected by type, size, or duration of drainage [55]; thus mode of drainage should be dictated by surgeon and patient preference.

If an indirect approach is to be used, access is gained into a calyx adjacent to the hydrocalyx. Flexible nephroscopy is used to identify the stenosed infundibulum. The infundibulum is then balloon dilated or incised using the holmium laser in a manner very similar to the ureteroscopic approach. A ureteral stent is then placed across the narrow infundibulum with proximal coil in the hydrocalyx and distal coil in the ureter. If it is not technically possible to place a ureteral stent, a percutaneous nephrostomy tube is placed across the dilated infundibulum into the hydrocalyx.

Potential complications

Potential complications related to the percutaneous treatment of infundibular stenosis are similar to those found with treatment of a calyceal diverticulum, but additionally include bleeding and restenosis. All efforts to avoid pulsatile vessels should be made at the time of the procedure. Minor-to-moderate bleeding can be controlled with the laser or point coagulation if needed, but is rarely necessary. Most minor bleeding should be allowed to resolve spontaneously to limit the risk of scar formation that can occur with excessive energy deposition.

Outcomes

The true outcome for the treatment of infundibular stenosis is unknown, as most reports are limited to small case series and are mixed with patients with calyceal diverticulum. Of the reported series with limited follow-up, the success rate is low at 60–80% [55, 66–68]. However, the type of treatment (i.e. balloon dilation,

Table 25.1 Bosniak radiographic classification of renal cysts and risk of malignancy.

Category	Description	Malignancy risk
I	Simple, thin walled without septa, calcifications, or solid components.	<1%
	Does not enhance with contrast and measures as water density	No follow-up required
II	Thin walled cyst with a few thin (<1 mm) septa with or without fine calcifications. Uniformly high-attenuation (>20 HU) lesions of <3 cm with sharp margins that do not enhance	3%
IIF	Multiple thin septa. Septa are thicker than hairline or slightly thick walled. Calcifications may be nodular and thick without contrast enhancement. No enhancing soft tissue elements	5–10% Follow-up recommended
	Intrarenal nonenhancing high attenuation renal lesions of ≥3 cm	
III	Indeterminate cystic masses that have thickened irregular walls or septa that enhance.	40–60% Surgical excision recommended
	Thick irregular calcifications	
IV	Cystic soft tissue masses that enhance.	>80%
	Irregular margins/prominent nodules	Surgical excision recommended

incision alone, incision plus dilation, etc.), the cause of the infundibular stenosis (i.e. iatrogenic, vascular, infection, etc.), and time of follow-up must be considered. No treatment method has been evaluated extensively enough to lead to one surgical approach being recommended over another.

Post-treatment evaluation

Since infundibular stenosis is such a rare condition, currently no clear standardized follow-up protocol has been established. We recommend that the treated infundibulum be stented either with a ureteral stent or percutaneous nephrostomy tube for 4–6 weeks post intervention. Urine culture should be negative prior to stent removal. If the urine culture is positive for infection, an appropriate course of antibiotics should be administered prior to stent or nephrostomy tube removal. After stent or nephrostomy tube removal, we recommend repeat contrast imaging of the affected kidney with either an excretory urogram or CT urogram at 4–6 weeks. If there is no evidence of recurrent stenosis, then the patient should be followed with yearly ultrasound imaging.

Symptomatic renal cysts

Simple renal cysts are commonly encountered on routine abdominal imaging and are seen as noncommunicating fluid-filled structures arising from the renal parenchyma. The incidence of renal cysts increases with age such that by age 40 years 27% of adults have renal cysts and 61% by 80 years [69]. Cysts are more common in men than in women and can be associated with a genetic predisposition, as with adult polycystic kidney disease (APKD). The majority of cysts are clinically insignificant and do not require treatment [70]; despite the fact that they can increase in number and size over time. Should a cyst become symptomatic, it may do so secondary to compression of the renal collecting system or adjacent organs, infection, or bleeding. Patients with symptomatic renal cysts may present with hematuria, flank pain, or even fever if infected. An association between renal cyst disease and hypertension has also been made; however, the exact causal relationship is uncertain [71].

Diagnosis

In general, simple renal cysts are benign, but more complex cysts can harbor a significant risk of malignancy. The appearance of the cyst on CT, magnetic resonance imaging (MRI), or ultrasound can help predict the likelihood of underlying malignancy and can be scored using the Bosniak classification (Table 25.1). In general, the diagnosis of a cyst can be made confidently with ultrasound, MRI, or CT alone. If there is concern for an infected cyst, it should percutaneously aspirated and the fluid sent for culture. An excretory urogram or CT urogram may be helpful if compression of the underlying collecting system is suspected. The differential diagnosis for a renal cyst includes calyceal diverticulum, hydrocalyx, ureteropelvic junction obstruction (UPJO), and cystic renal mass.

Treatment

Multiple options exist for the treatment of symptomatic simple renal cysts, including percutaneous puncture/aspiration with sclerotherapy, retrograde ureteroscopic puncture, laparoscopic or open unroofing, and percutaneous resection. Initially, open cyst decortication or even nephrectomy was the preferred treatment of symptomatic cysts. Due to the morbidity associated with the open surgical approach to simple renal cysts, percutaneous aspiration with injection of a sclerosing agent (alcohol, quinacrine, glucose, iophendylate, bismuth phosphate, or phenol) became a minimally invasive treatment alternative [72]. Although short-term results report a 75–100% satisfactory outcome with percutaneous aspiration and sclerotherapy, long-term data greater than 5 years are lacking [55]. The role of percutaneous aspiration and sclerotherapy has been further limited by reports of significant complications, including UPJO, cyst abscess, fever, pain, and recurrence [73, 74].

There have been reports of retrograde treatment of renal cysts via ureteroscopy but these are limited [75]. The ureteroscopic approach is the least invasive, but is limited to small cysts adjacent to the collecting system. With the ureteroscopic approach, the urothelium separating the collecting system from the cyst is opened using a holmium laser, allowing for internal marsupialization. To avoid injury to the renal vessels, the cyst should not be too centrally located.

Laparoscopic unroofing is ideal for large anteriorly located simple renal cysts [76, 77]. One advantage of laparoscopic ablation is the ability to identify surrounding structures, such as the renal hilum or aberrant vessels. Despite these advantages the laparoscopic approach is more invasive than percutaneous procedures, requiring multiple port sites and potentially longer operative times [72].

Percutaneous resection and intrarenal marsupialization was reported in 1984 [78]. Multiple follow-up series have confirmed the efficacy and safety of the procedure [72, 79–81]; however, long-term outcomes are limited [81]. Our experience with percutaneous resection of renal cysts has lead us to consider the procedure for all symptomatic renal cysts that appear accessible percutaneously. This approach is especially attractive if there are concomitant renal stones requiring treatment.

Technique

The cyst can be accessed either using ultrasound guidance or fluoroscopic guidance. If fluoroscopic guidance is used, an external ureteral catheter is placed prior to prone positioning, to allow for retrograde installation of contrast. The area of the collecting system distorted by the renal cyst is considered the percutaneous target. Standard triangulation technique is then used to percutaneously access the cyst. The aspiration of fluid confirms intracyst positioning of the needle; the fluid should be sent for cytology and culture. Access to the cyst is then achieved in an identical fashion as for a calyceal diverticulum using a removable core 0.035-inch J wire coiled inside the lumen of the cyst. An 8/10F sequential dilator is used to place a second safety wire and a balloon dilating system is used to position the 30F access sheath into the lumen of the cyst.

If the cyst is not large enough to be percutaneously accessed directly, then indirect access can be utilized. Using the indirect access technique, a calyx adjacent to the cyst is accessed percutaneously in the standard fashion. The cyst is then approached from the collecting system, either by withdrawing the sheath from the collecting system and visually advancing it into the adjacent cyst, or using flexible nephroscopy and visualizing the cyst endoscopically from the collecting system. If flexible nephroscopy is utilized, the cyst is simply marsupialized into the collecting system using a holmium laser, as previously described for the ureteroscopic approach.

Regardless of access, once the sheath is inside the lumen of the cyst, the irrigation fluid is switched to 1.5% glycine. Using a rollerball electrode, the entire cyst wall is fulgurated. Electrocautery should be set at the lowest possible settings to allow for blanching of the cyst wall without perforation [72]. After fulguration a portion of the cyst wall is excised using grasping forceps or loop resection for marsupialization to the retroperitoneum. We do not routinely marsupialize to the collecting system, since reports indicate recurrence rates are not decreased with this procedure [72]. Once the procedure is completed, an 8 or 10F locking Cope loop nephrostomy tube is left inside the cavity overnight, with removal the next day. Another option for drainage is to place a red rubber catheter in the cyst overnight if the cavity is not large enough for the loop nephrostomy tube.

Potential complications

Potential complications of percutaneous resection of simple renal cysts are similar to those found with treatment of a calyceal diverticulum, but also include recurrence of cyst or incomplete obliteration with recurrence of symptoms.

Outcomes

Reports on percutaneous resection of simple renal cysts are limited. In a recent series by Kang *et al.*, nine patients with symptomatic renal cysts were managed with percutaneous resection with a mean follow-up of 21 months (8–25 months) [72]. There were no complications reported in the series. Complete resolution of pain was noted in 89% of patients and complete obliteration of the cyst in seven patients (78%). Similar initial short-term results have been reported by Gelet *et al.* who found complete resolution of the cyst in 60% of patients and only a 15% recurrence rate [80]. Hubner *et al*. initially reported a 57% cyst resolution rate and 7% recurrence rate at short-term follow-up [82]. However, when 10 of these patients were followed for a mean of 45.7 months (26–66 months), 50% of the cysts were detectable or near their pretreatment size [81]. Interestingly, none of the patients experienced recurrence of their original symptoms despite recurrence of the cyst.

Post-treatment evaluation

There are no standard follow-up recommendations for patients treated with percutaneous resection of a simple renal cyst. We recommend a renal ultrasound and urinalysis 3 months post procedure. The patient can then be followed up as needed for symptom recurrence.

Conclusions

Percutaneous treatment of calyceal diverticula, infundibular stenosis, and symptomatic simple renal cysts can be a safe, effective treatment alternative in appropriately selected patients. Although experience is limited with these percutaneous techniques, long-term data support the role of percutaneous treatment of calyceal diverticula as initial intervention. Even with limited data to support long-term success, the low complication profile for percutaneous treatment of hydrocalyx associated with infundibular stenosis and symptomatic renal cysts also supports its role as a first-line minimally invasive treatment option.

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CHAPTER 26

Percutaneous Instillation of Chemolytic, Chemotherapeutic, and Antifungal Agents

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Introduction

Percutaneous instillation of topical agents started in 1924 when Crowell disintegrated a cystine stone by instillation of alkaline solution into the kidney [1]. Before the advent of miniaturized fiberoptic flexible ureteroscopes and nephroscopes, the nephrostomy tube provided a conduit for direct instillation of topical agents into the collecting system, thus minimizing systemic side effects. Chemolytic agents for stones were the original and most common agents. Currently, two other categories of topical instillation agents are used; chemotherapeutic/immunotherapeutic agents as adjuvant treatment for upper tract transitional cell carcinoma (TCC), and antifungal agents.

An advantage of direct instillation when compared with systemic therapy is longer duration of direct contact of the topical agents with the collecting system, which allows topical agents to reach the target organ in appropriate concentrations. This leads to shorter therapy and avoidance of harmful systemic side effects [2]. In addition, these topical agents can be administered in patients with compromised renal function, inadequate urinary drainage, and high operative risk due to comorbidities [3]. However, it is important to note that there are several contraindications to initiating or continuing percutaneous instillation of topical agents. These include positive urine culture, febrile patient, persistent flank pain, extravasation of irrigation fluid, or intrapelvic pressure greater than 25 cmH_2O [4].

With recent advances in endourologic technology, indications for instillation of topical agents have evolved and can be very useful for select patients. Although principles of instillation of topical agents into the collecting system are simple, minor errors in technique can result in catastrophic complications. Therefore, in addition to the urologist, both the nursing staff and the patient should be aware of the tell-tale signs of complications and if they arise the treating physician should be informed and the instillation stopped immediately. Therefore, urologists should be familiar with techniques of instillation, indications and contraindications, success rates, and any potential side effects.

In this chapter, chemolytic agents (for stones), chemotherapeutic/immunotherapeutic agents for upper tract TCC, and antifungal agents will be reviewed.

Techniques of irrigation/instillation

Topical instillation of agents into the collecting system depends on the principle of free flow of the solution throughout the collecting system, thus providing a continuous milieu of irrigant solution to the stone, upper tract TCC, or fungal ball. This can be achieved through several techniques: either retrograde fashion, percutaneous antegrade fashion, or a combination of both.

Retrograde approach

The retrograde technique is the most simple and least invasive. It is done through a single ureteral catheter

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that is advanced beyond the level of the lesion or stone. The main disadvantage of this technique is the limitation of outflow through or around this small stent, which can result in a rapid elevation of intrapelvic pressures. Therefore, this technique of irrigation is not recommended. In an attempt to avoid this complication, Kuwahara *et al*. used a computer-controlled, pressure-monitor intermittent pump (Figure 26.1A) [5]. This pump infuses fluid for 1 min, holds for 30 s, and then drains for 9 s. If the pressure increases beyond the preset limit (15 $\mathrm{cmH_2O}$), the infusion stops. If the pressure increase is sustained for 5 s, the drainage valve opens. This system has not been widely used because it is prohibitively expensive; as such its safety and efficiency have not been properly evaluated. Without such a pump, a single ureteral catheter for irrigation is not recommended.

Several other techniques of retrograde instillation have been described. Dormia *et al*. [6] utilized concentric catheters placed in the ureter to facilitate the outflow from the kidney into the bladder (Figure 26.1B). Another less efficient technique is vesicoureteral reflux in a patient with an indwelling ureteral stent postureteral meatotomy [7]. Recently, a high-flow low-pressure irrigation system was described that uses an 8F pigtail catheter through a 12/14F ureteral access sheath (Applied Medical Systems, Rancho Santa Margarita, CA, USA). In an *in vitro* study, this system was found to be associated with significantly higher flow rates and lower pressures when compared with a single nephrostomy tube without ureteral catheters [8].

Antegrade approach

The ideal inflow and outflow is achieved in a percutaneous antegrade fashion through the use of two nephrostomy tubes, e.g. two Malecot catheters (16 or 18F) (Figure 26.1C). This configuration is versatile and can be used in most patients. In patients with struvite stones, which tend to form large, irregular pieces on fragmentation, an endopyelotomy stent (14/8.2F) provides excellent two-way outflow, decreases the volume of fragments that enter the ureter, and prevents its obstruction [9] (Figure 26.1D). Another method of preventing ureteral obstruction is the insertion of an indwelling double pigtail catheter when two Malecot nephrostomy tubes are used. Yet a simpler method of inflow and outflow in antegrade fashion through two nephrostomy sites is achieved with a circle tube (Figure 26.1E).

Two coaxial techniques of irrigation have been described. First, Hare and McOmish described a renal pelvic lavage set to irrigate different areas of the pelvis through a single nephrostomy site allowing both inflow and outflow [10] (Figure 26.1F). Once the Teflon sheath is in place, an inner 6.3 or 8.3F pigtail catheter is directed at the stone for inflow. Outflow, which is limited, occurs through the surrounding sheath and down the ureter. The second coaxial technique works well for upper ureteral stones [11, 12]. It is set up by inserting either a 5F ureteral or angiogram catheter over a wire through the lumen of an 18F Foley catheter, which serves as a nephrostomy tube (Figure 26.1G). The small inner catheter, which provides inflow, can be advanced so that its tip is adjacent to the stone, and the Foley catheter provides outflow. A simpler technique of irrigating the renal pelvis through a single nephrostomy site is the use of a three-way Foley catheter [13].

Combined approach

A combination of the antegrade and retrograde techniques can be achieved through the insertion of a percutaneous nephrostomy tube and ureteral catheter. The nephrostomy tube acts as an ideal outflow, while the ureteral catheter is used for instillation (Figure 26.1H). However, using both a ureteral catheter and a nephrostomy tube will severely reduce patient mobility. Therefore, a modified approach uses a nephrostomy tube to instill agents and an indwelling double pigtail ureteral catheter as a drainage catheter. The drawback of this approach is that the outflow through a ureteral catheter is much less efficient than that through a nephrostomy tube, and this modification is only ideal for small stones that dissolve quickly, e.g. uric acid stones.

Safety principles

All of the techniques described above should follow appropriate safety principles. Patients should have preoperative urine cultures and be treated with culture-specific antibiotics. Urine cultures should be negative prior to initiating irrigation and patients should be kept on antibiotics throughout the irrigation. Additionally, once the tubes are inserted, contrast studies should be performed 24 h later to rule out extravasation.

The irrigation with warm saline should start slowly at a rate of 30 mL/h. Providing the patient remains pain free and afebrile, the rate can be doubled every 2–4 h until the target rate of 120 mL/h is reached [13]. After 12–24 h of saline irrigation, the active agent is instilled at a rate of 30 mL/h and increased sequentially to 120 mL/h. Warming the irrigation solution has several advantages: it is more comfortable for the patient, avoids hypothermia, and may increase the effectiveness of therapy [14–16].

It is important to include an intrapelvic pressure monitoring system in all of the techniques described above. If renal pelvic pressures are uncontrolled, pyelovenous and pyelolymphatic backflow can lead to systemic absorption. Subsequently, the patient may suffer

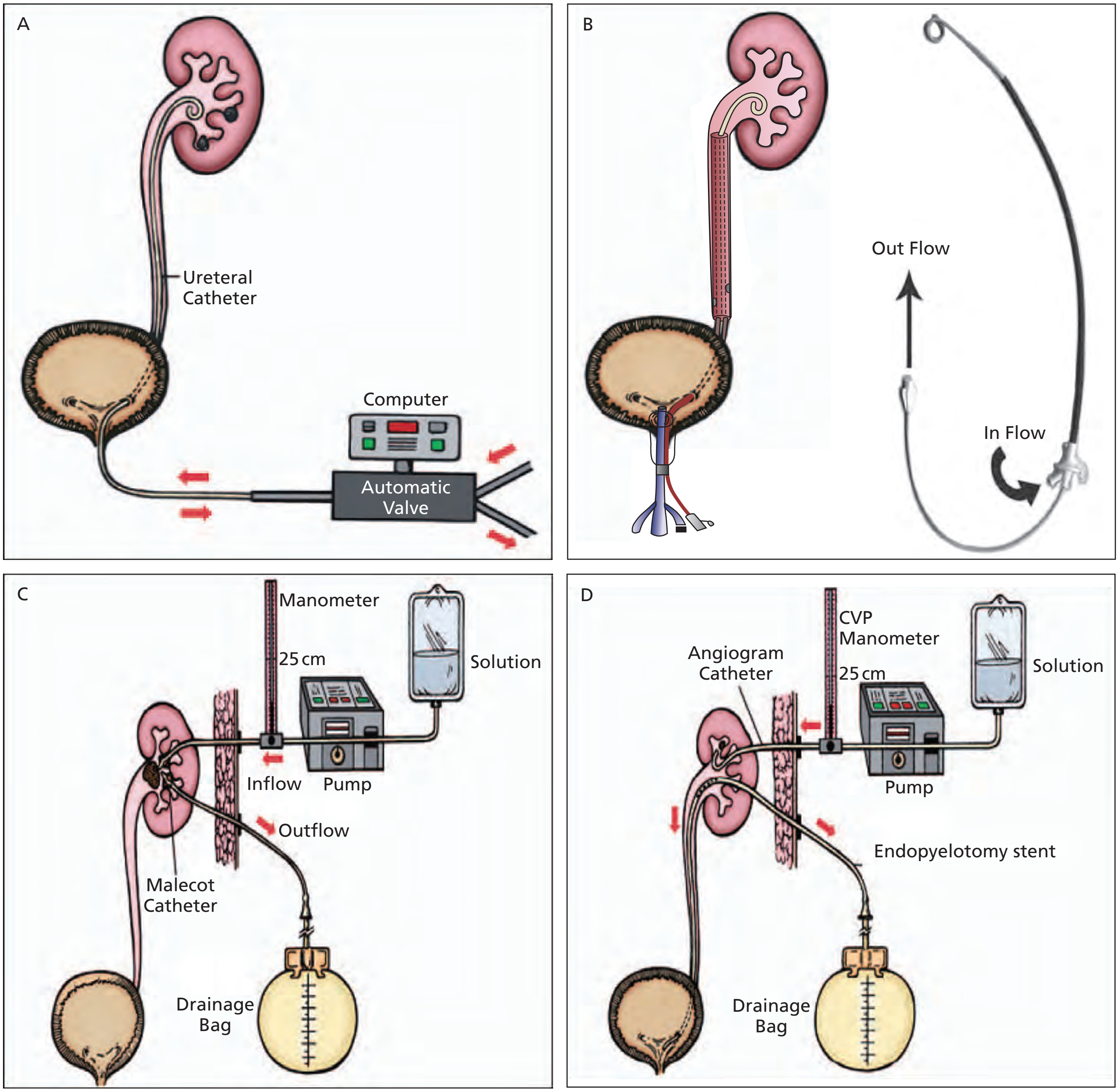
A
Ureteral Catheter
Computer
Automatic Valve
B
Out Flow
In Flow
C
Manometer
25 cm
Solution
Inflow
Pump
Outflow
Malecot Catheter
Drainage Bag
D
CVP Manometer
Angiogram Catheter
25 cm
Solution
Pump
Endopyelotomy stent
Drainage Bag

Figure 26.1 Irrigation configurations for chemolysis. (A) Retrograde ureteral catheter with computer-driven inflow/outflow (adapted from Fried and Smith [13] with permission). (B) Concentric catheters in kidney, ureter and bladder for trans-ureteral irrigation (adapted from Dormia *et al.* [6]; and Collins *et al.* [8]). (C) Dual Malecot catheters irrigation. (D) Nephrostomy inflow and universal/endopyelotomy stent outflow irrigation for struvite stones.

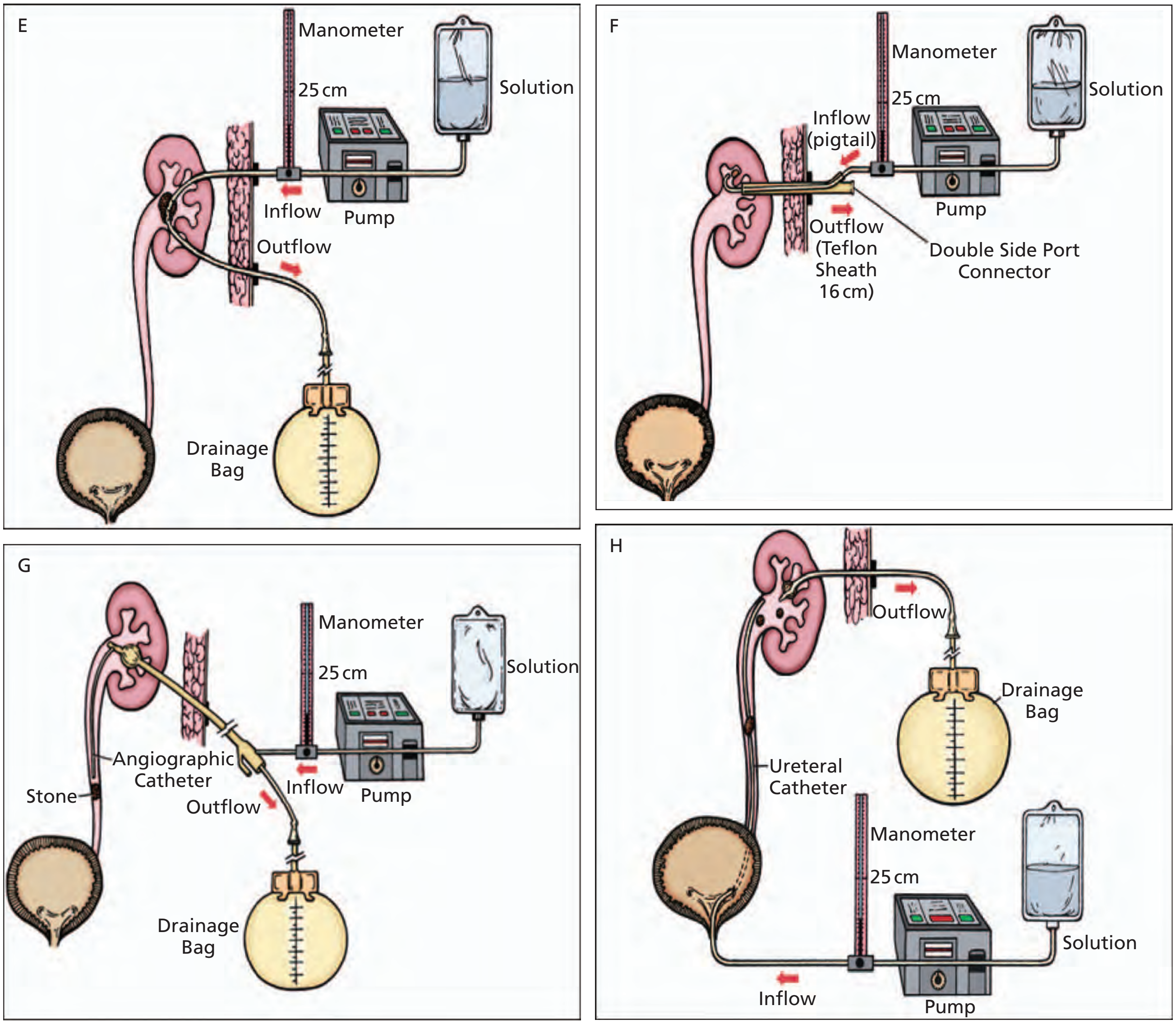
E
Manometer
25 cm
Solution
Inflow
Pump
Outflow
Drainage Bag
F
Manometer
25 cm
Solution
Inflow (pigtail)
Pump
Outflow (Teflon Sheath 16 cm)
Double Side Port Connector
G
Manometer
25 cm
Solution
Angiographic Catheter
Stone
Outflow
Inflow
Pump
Drainage Bag
H
Outflow
Drainage Bag
Ureteral Catheter
Manometer
25 cm
Solution
Inflow
Pump

Figure 26.1 *Continued* (E) Circle tube for irrigation chemolysis. (F) Coaxial technique of ureteral catheter through a Foley catheter. (G) coaxial technique of ureteral catheter through a Foley catheter. (H) retrograde ureteral catheter inflow and nephrostomy outflow.

agent-specific systemic toxicities, or changes in serum chemistries when the irrigant solution is nontoxic [17]. Therefore, to prevent pyelovenous backflow, the intrapelvic pressure should not be allowed to rise above 25 cmH_2O [18]. The simplest method uses a central venous pressure (CVP) manometer connected to the inflow line, which is both readily available and familiar to nursing staff. Unfortunately, this is an open system that is amenable to contamination or overflow spills. Furthermore, it requires continuous monitoring since there is no preset pressure alarm or automatic shut-off for high pressures (more than 15 cmH_2O). A better alternative is a closed continuous infusion pump that provides a continuous display of the intrapelvic pressure and will sound an alarm and shut off if the preset limit is exceeded (CareFusion, San Diego, CA, USA) [6]. Regardless of which pump is used; the patient should be taught how to immediately turn off the pump in case of flank pain or fever.

Chemolysis of urinary calculi

Stone dissolution through chemolysis remains an option in the treatment of urolithiasis, even with the advent of more sophisticated modalities. Chemolytic agents can achieve benefit through either primary or secondary dissolution. Primary dissolution is when chemolytic agents are used as initial therapy to dissolve stones completely or partially. This may be an option in patients unfit for general anesthesia. Secondary dissolution may be useful in patients with residual fragments after some other primary therapy. In this context, chemolysis may render the patient stone free, thus reducing the potential for recurrences or more invasive interventions.

For effective chemolysis, the irrigant must have several important characteristics: (1) be compatible with biologic tissue and of limited toxicity; (2) have minimal systemic absorption in order to limit potential toxicity; (3) dissolve calculi and their fragments quickly to reduce treatment burden for the patient; and (4) do not precipitate causing secondary stone formation. Additionally, an ideal irrigation system must provide for free flow of irrigant to a targeted area, while maintaining low renal pelvic pressures to prevent bacteria from entering the bloodstream and avoiding renal damage [17].

Unfortunately, stone dissolution through chemolysis has several limitations. Some stones may require long treatment periods, which may necessitate prolonged hospital admission and patient discomfort. The efficacy of stone dissolution is dependent on many stone-specific factors. For example, uric acid and struvite amorphous minerals dissolve much faster than highly crystalline salts such as calcium oxalate. Likewise, stone size and shape will determine rate of dissolution. Large stones will dissolve more slowly than the same volume of smaller stones as the surface area is greater in the latter [19, 20]. These variables can make it difficult to predict the necessary length of treatment *a priori*. In addition, the choice of chemolytic agent will depend on stone type and stone composition must be determined prior to chemolysis. When stone fragments are not available, surrogate methods of determining stone composition, such as computed tomography (CT) characteristics or the composition of previous stones, must be used to determine the agent of choice [17, 21, 22].

Uric acid stones

Almost all individuals who form uric acid stones have persistently low urinary pH (<5.5) and most excrete normal amounts of uric acid [23, 24]. The acid–base properties of uric acid stones render them amenable to dissolution therapy. Uric acid is a weak organic acid with a pKa of 5.35 in urine at 37°C. At this pH, half is present as the undissociated acid and half as the urate anion. Since urate is more soluble than uric acid, raising the urinary pH within the physiologic range has a profound effect on how much uric acid/urate can be dissolved. For example, a urine sample containing 800 mg/L total urate will have 600 mg/L uric acid at pH 5.0 but less than 100 mg/L at pH 6.5. The latter figure is well below the solubility limit of uric acid so that a solution above pH 6.5 can dissolve a uric acid calculus [18]. Any solution above pH 7 is likely to be effective but higher urinary pH solutions may have a tendency to calcify the stone, particularly if sodium bicarbonate is used as the base [25]. Increasing the urinary volume further enhances the therapeutic efficacy of alkaline medications [26]. In addition, decreasing the oral purine load from dietary sources can effectively help treat patients, because 40–60% of excreted uric acid is derived from exogenous sources. Regardless of the method chosen, urine pH should be monitored with pH strips to optimize therapy. It is also important to follow serum and urine uric acid levels, especially in those with recurrent calculi.

Systemic agents

Systemic alkalinization is generally achieved with oral or intravenous therapy. The most popular agent is sodium bicarbonate at a dose of 650–1000 mg three to four times daily. An alternative preparation, if the sodium load is too great, is potassium citrate administered at 15–30 mEq three to four times daily. Intravenous alkalinization is more effective than the oral route; urinary pH is elevated more quickly, to a higher degree, and more reliably. This technique, however, is typically reserved for hospitalized patients with acute episodes of renal colic and obstruction. One-sixth molar lactate solution has been demonstrated to dissolve uric acid stones even when they are causing ureteral obstruction [27]. Lactated Ringer's solution with one to two ampoules of sodium bicarbonate added per liter is an acceptable alternative. The infusion rate (usually 50–100 mL/h) is titrated to a urinary pH of 7.0–7.5, which occurs within 4 h. Cardiac and hypertensive patients must be monitored for the large sodium load in these solutions.

Several other oral therapies have been suggested to facilitate dissolution therapy. Sterrett *et al*. demonstrated that acetazolamide, a carbonic anhydrase inhibitor, was effective in increasing the urinary pH in patients with uric acid and cystine stone formation who were already taking potassium citrate [28]. Caution must be taken when prescribing acetazolamide because it can be poorly tolerated and can induce calcium phosphate stone formation. A dose of 250 or 500 mg is taken at bedtime to maintain urine alkalinity during sleep. In cases of hyperuricosemia and hyperuricosuria, allopurinol should be added to inhibit the production of uric acid through inhibition of the enzyme xanthine oxidase.

Chemolytic agents

Since the urinary pH can usually be raised to at least 6.5 with oral or intravenous alkaline salts, medical therapy is ordinarily the treatment of choice for uric acid stones

[18, 24, 26]. There are clinical situations in which oral or intravenous therapy is not possible, such as in patients who are noncompliant, or have chronic renal failure or an ileostomy, and these patients may benefit from direct chemolytic therapy. Additionally, if a large amount of residual fragments is present after an initial therapy, direct chemolysis is a viable option.

The most common alkalinizing agents are sodium bicarbonate solution (pH 7.0–9.0), tromethamine (THAM, pH 8.6), and THAM-E (pH 10.5). Sodium bicarbonate solution is inexpensive and can be prepared easily by adding two to four ampoules (44 mEq each) to each liter of irrigant solution (normal saline solution or water). With this solution, there is no value in increasing the final urinary pH to greater than 7.5. In fact, higher pHs may be detrimental to stone dissolution because phosphatic and sodium urate encrustations may form a coating on stones [29]. The THAM solutions do not cause such mineral deposits and in animal models have been shown to cause more rapid stone dissolution than sodium bicarbonate [25]. THAM-E is slightly more effective than THAM because of its higher pH, but it causes more irritation and potential damage to the epithelium [30, 31]. Therefore, for uric acid chemolysis, THAM appears to be the agent of choice [18] (Table 26.1).

If a uric acid staghorn calculus is present, pretreatment with extracorporeal shock-wave lithotripsy (ESWL) may increase the stone surface area and facilitate dissolution. Unlike struvite and cystine stones, it is unusual to need prolonged irrigation to manage uric acid stones.

Cystine stones

Cystinuria is an autosomal recessive disorder of dibasic amino acid transport in the kidney that leads to crystallization of poorly soluble cystine in the urine [32]. Between 3% and 59% of those who are homozygous for the trait will produce stones [33]. The disease is more severe in men than in women in terms of early appearance and number of stones. Although the incidence of cystine stones is only about 0.9%, they rank third in terms of rate of recurrence [34]. Treatment of cystine stones continues to be one of the most challenging therapeutic dilemmas in endourology because of their high frequency of recurrence, resistance to ESWL, difficulty in localization, and the inadequate effect of oral chemolysis [35].

Due to the difficulties in treating cystine stones, much emphasis has been placed on prophylaxis. The solubility of cystine, like all amino acids, is pH dependent. Therefore, the production of alkaline urine can prevent cystine precipitation in the urine. A significant increase in cystine solubility begins to occur when urinary pH exceeds 7. For example, at pH 8, cystine solubility increases to approximately 1000 mg/L [36]. However, a significant drawback of urinary alkalinization is increased risk for calcium phosphate precipitation with pH above 7.5 [37]. For this reason, a urinary pH of 7.5 is recommended [36]. It is recommended that this alkaline urinary pH must be maintained at night while the patient sleeps. The use of the potassium salts of citrate and bicarbonate may be more effective than the analogous sodium compounds because the presence of a sodium ion increases cystine excretion in the nephron. As such, a low sodium diet may be useful in the management of cystinuria [38].

Cystine is composed of two cysteine molecules joined by a disulfide bond and its dissolution requires alkalinization and splitting of the disulfide bond. This can be accomplished through either oral therapy or direct chemolytic therapy. D-Penicillamine, the first oral agent used for cystine stones, is a disulfide exchange resin that facilitates splitting of the disulfide bond through the thiol exchange reaction, forming mixed disulfides, and also decreases urinary excretion of cystine. The exchange reaction forms penicillamine disulfide–cysteine, which is 50 times more soluble than cystine [39] and is readily cleared through the urine. D-Penicillamine is administered as 1–2 g in four divided doses, starting with a small dose and increasing as tolerated. Side effects of the drug include leukopenia, thrombocytopenia, gastrointestinal disturbances, skin rashes, proteinuria and nephrotic syndrome, neuropathies, and abnormalities of taste and smell. D-Penicillamine has been reported to dissolve even large stones when combined with alkalinization but its potential side effects severely limit its usefulness.

α-Mercaptopropionylglycine (MPG) is another disulfide exchange resin with fewer side effects than D-penicillamine; it also appears to be more effective [40]. The usual dose of MPG is 600–1800 mg/day in four divided doses. Simultaneous treatment with oral sodium bicarbonate increases the effectiveness of this preparation because the disulfide exchange reaction is more active at higher pH levels.

Oral acetylcysteine, MPG, and D-penicillamine are much more effective in preventing the formation of cystine calculi than in dissolving them. When used for direct chemolysis, however, they are potent dissolution agents. During direct irrigation, the solution bathing the stone will have a much higher concentration of the active agent. The pH of the solution is likewise more easily controlled, thereby facilitating the thiol exchange reaction [13].

Chemolysis monotherapy would require lengthy durations of irrigation for most stones. Approximately 9 days are required to dissolve a 1-cm cystine calculus. This irrigation time could be diminished with combined therapy with ESWL or percutaneous nephrolithotomy

Table 26.1 Results of direct chemolysis for uric acid and cystine stones.

Uric acid calculi				
Study	Irrigation solution	Dissolved/ attempted	Duration of irrigation (days)	Adjuvant treatment
Chemolysis alone				
Hedgcock *et al*. [12]	Sodium bicarbonate	11/11	3–21	
Gordon *et al*. [151]	THAM	3/3	7–10	
Ansari *et al*. [152]	Sodium lactate	3/3	7–14	
ESWL and chemolysis				
Lee *et al*. [153]	Sodium bicarbonate	5/8*	2–7	
Cystine calculi				
Hayase *et al*. [154]	THAM-E	0/3	25–37	3 partial dissolution, 1 nephrolithotomy
Crissey and Gittes [155]		1/2	5	1 ureteral, 1 renal stone
Kachel *et al*. [156]	THAM-E with/without N-acetylcysteine	3/9	–	3 partial dissolution, ESWL with/without PCNL
Dretler *et al*. [157]		7/11	6–42	1 partial dissolution
Aabech and Andersen [35]		2/2	3–9	Surgery with/without ESWL
Smith *et al*. [158]	N-Acetylcysteine + sodium bicarbonate	1/1	26	
Schmeller *et al*. [19]		1/1	30	
Kane *et al*. [65]	Mercaptopropionylglycine	5/5	24–88	1 pyelolithotomy, 1 bladder stone, urokinase added to irrigant
Stark and Savir [159]	Penicillamine	1/1	180	1 pyelolithotomy

*Three patients had only small clinically insignificant fragments.
ESWL, extracorporeal shock-wave lithotripsy.

(PCNL), which reduce the stone burden and increase the surface area of the remaining fragments. Stones less than 1.5 cm in diameter may be treated initially with ESWL. If successful fragmentation occurs, repeat ESWL or medical management may be sufficient as follow-up therapy. Otherwise chemolysis alone or combined with PCNL is appropriate. For stones greater than 1.5 cm, PCNL is the initial procedure of choice. Residual calculi, which are likely to remain, can be effectively treated with chemolysis and additional PCNL or ESWL sessions. Simultaneous oral therapy should be implemented in all cases [13] (Table 26.1).

If the stones appear extremely resistant to therapeutic measures, the possibility of a mixed stone should not be overlooked. Hydroxyapatite, struvite, calcium oxalate, and calcium phosphate contaminants have been present in 14–46% of cystine calculi analyzed in some studies [41].

In summary, although cystine urinary calculi continue to present a formidable challenge to urologists, successful eradication without open surgery may be accomplished with chemolytic techniques in conjunction with minimally invasive fragmentation procedures.

Struvite stones

Struvite stone formation typically occurs in patients with recurrent urinary tract infections (UTIs) and retained urine. Predisposing factors include urinary tract obstruction, chronic indwelling catheter, urinary diversion, and neurogenic voiding dysfunction [42]. Most commonly, staghorn stones are composed of a mixture of struvite (magnesium ammonium phosphate) and calcium carbonate apatite. In fact, hypercalciuric patients begin with calcium oxalate stone formation and develop superimposed infection with struvite deposition [43, 44]. Struvite calculi are typically referred to as infection stones because of their strong association with UTIs. Silverman and Stamey identified *Proteus* as the dominant microorganism in 72% of isolates from stone formers [45]. Urease produced by such bacteria leads to hydrolysis of urea to ammonium, hydroxide, and bicarbonate, which increase the urine pH (>7.2). This alkaline urine, in the presence of trivalent phosphate, results in struvite crystal formation [46]. Other urease producers include *Klebsiella*, *Pseudomonas*, and *Staphylococcus* species [45, 47]. However, the most ubiquitous uropathogen, *Escherichia coli*, only rarely produces urease and thus is an infrequent cause of staghorn calculi [48].

Struvite stones are characterized by their large size and exceptionally rapid growth. It is not uncommon for a staghorn calculus to involve the entire renal pelvis and calyces, nor for it to be formed within a 4-week period [42].

Management of struvite stone disease is one of the most frustrating problems in urology as efforts to eradicate such stones often have suboptimal success rates. The problem is not only ridding the patient of the calculi but also sterilizing the urine. Persistence of infection was estimated to occur in approximately 40% and is believed to be responsible for many of the stone recurrences [49]. The presence of small stone particles with embedded bacteria serves as a nidus for new stone formation and rapid recurrences. Therefore, postoperative irrigation therapy has been proposed to potentially reduce struvite stone recurrences [50, 51]. Oral chemolysis is available primarily in the form of urease inhibitors. Acetohydroxamic acid (AHA), the most commonly used agent, was identified as an irreversible urease inhibitor by Fishbein and Carbone [52]. The drug acts synergistically with several antibiotics, sterilizing the urine more rapidly. Its clinical usefulness has been demonstrated in double-blind studies but serious side effects precluded its use in patients in spite of these being reversible and dose related [53–55]. The usual dose is 250 mg orally three times daily to be reduced to twice daily for mild renal impairment, and it is contraindicated in patients with severe renal insufficiency and in pregnancy. The most commonly reported side effects are hemolytic anemia, neurosensory deficits, and thrombophlebitis. Headache, gastrointestinal upset, weakness, and flushing sensation after alcohol ingestion have also been reported [56]. Yet, it is the only Food and Drug Administration (FDA)-approved urease inhibitor available today [57].

Systemic oral chemolytic agents are seldom effective in reducing stone burden on their own and direct chemolysis of struvite calculi is a far more effective method of dissolution. Suby *et al*. presented the first application of direct chemolysis to struvite calculi; however, the initial solution was too irritant for urothelium to be clinically used [58, 59]. Suby's solution G, formed by the addition of magnesium to the previous formulation, has similar efficacy but decreased mucosal irritability (Table 26.2). Hemiacidrin (Renacidin), a modification of Suby's solution, is a multielectrolyte solution introduced by Mulvany [60] (Table 26.2). The acids present in this solution provide hydrogen ions and citrate to form soluble complexes with phosphate (phosphoric acid) and calcium (calcium citrate) from the stone (Table 26.3). Magnesium undergoes ion exchange with calcium present in the stone, enhancing dissolution while reducing irritation. The solubility of struvite is markedly increased at a pH less than 5.5, which occurs with each of the three variants of Suby's solution. This finding was confirmed in an *in vitro* study by Jacobs *et al*. [61].

Table 26.2 Composition of different chemolytic agents.

	Suby's solution		
Compound	G	M	Renacidin
Citric acid (g)	32.3	32.3	28.2
Magnesium oxide (g)	3.8	3.8	0
Sodium carbonate (g)	8.84	8.84	0
Calcium carbonate (g)	0	0	1.0
D-Gluconic acid (g)	0	0	5.0
Magnesium hydrocarbonate (g)	0	0	14.8
Magnesium acid-citrate	0	0	2.5
Water (mL)	1000	1000	1000
pH	4.5	4.0	4.0

Infectious complications are known to occur as a result of dissolution therapy. Renacidin and Suby's solutions have been implicated as the cause of urosepsis and death due to the release of large amounts of viable bacteria from stones as they dissolve. Therefore, it is critically important to stop treatment once fever occurs and until any infection has been adequately treated. The presence of catheters and extensive use of antibiotics can also facilitate fungal infection. Replacing the irrigation fluid with amphotericin B (50 mg/500 ml H_2O) at a rate of 125 mL/h generally clears the funguria in less than 72 h. Chemolysis irrigation can resume once urine cultures have been negative for 24 h.

Calcium stones

Calcium-based calculi constitute about 80% of all urinary tract stone calculi, of which about 80% are calcium oxalate stones [62]. Yet, they are the least amenable to chemolysis. The strong acids required to dissolve this compound cannot be safely used in humans. Only chelating agents have successfully been used *in vivo* to

Table 26.3 Results of direct chemolysis of struvite calculi.

Irrigating solution	Primary (1°) or adjuvant (2°) therapy	Dissolved/ attempted	Duration of irrigation (days)	Comment
Suby's solution G				
Suby and Albright [59]	1°	3/7	10–90	Patients had ileal conduits
Smith *et al.* [11]	2°	1/1	5–9	
	1°	2/2	N/A	
	2°	1/1		
Renacidin				
Mulvaney [60]	1°	17/31*	N/A	Kidney/bladder/ureteral stones
Russell [160]	1°	2/2	10–13	
Kohler [161]	1°	4/5	14–115	
	2°	4/6	12–120	
Nemoy and Stamey [4]	1°	3/3	12–30	Prophylactic irrigation used
	2°	4/4	1–14	
Dretler *et al.* [80]	1°_	6/8	7–20	
Brock *et al.* [162]	1°_	3/4	2–9	Patients had ileal conduits
Rudman *et al.* [56]	1°	2/2	14–17	9% recurrence at 66-month follow-up
	2°	18–21	2–26	
Dretler and Pfister [17]	1°_	16/23	6–45	
Palmer *et al.* [163]	1°	7/9	6–69	Outpatient treatment performed
	2°	7/9	3–30	
Blaivas *et al.* [164]	2°	8/11	2–21	
Jacobs and Gittes [165]	2°	7/11	222	
Nemoy and Stamey [166]	2°	2/2	815	
Kleine *et al.* [167]	2°	8/9	434	
Silverman and Stamey [45]	2°	5/11	4.5 (avg)	
Spirnak *et al.* [20]	2°	9/11	2–8	ESWL 1.2 times per kidney
Angermeier *et al.* [168]	2°	3/3	1–8	ESWL and PCNL irrigation with pressure control pump
Total	1°	65/96	14(avg)	
	2°	77/100	9 (avg)	

*Includes partial dissolutions.
ESWL, extracorporeal shock-wave lithotripsy; N/A, not applicable; PCNL, percutaneous nephrolithotripsy.

dissolve these types of stones. Ethylene-diamine-tetra-acetic acid (EDTA) is the most commonly used solvent, and has had moderate success in humans [63, 64] in spite of the significant urothelial injury reported [65]. EDTA is a polyvalent molecule which binds calcium through its two amine and four carboxyl groups. This sequestration dissolves the calcium component of the stone, thus reducing stone burden. Complete stone dissolution of over 50% in 260 patients treated with EDTA was reported [66]. Early use of this solution after stone formation is associated with a better response rate. These authors also used 0.25% lyophilized papain to dissolve the matrix component of the stones. EDTA solutions are not widely used, primarily because they can cause urothelial injury.

Summary

In summary, the choice of chemolytic agent and method of administration is dependent primarily on stone composition and should be tailored to the individual clinical scenario. There are several chemical means to increase the solubility of a stone. Manipulation of the pH is most commonly used; however, other modalities include disulfide rearrangement and cation chelation [18]. Manipulation of pH works particularly well for uric acid stones since they are 11 times more soluble at a pH of 6.5 than of 5.0 [24, 67]. An effective therapeutic pH of slightly above 7.0 can often be achieved with oral therapy alone but direct chemolysis can be considered for large stone burden [68]. Struvite stones will dissolve at a pH of 4.9, but at a rate too slow to be clinically useful [69]. Therefore, other approaches, including systemic chemolysis with urease inhibitors or direct chemolysis with Ranicidin solution, should be considered. The solubility of cystine is increased in alkaline urine, but is higher than that required to dissolve uric acid (pH of 7.5). At this pH there is an increased the risk of secondary precipitation. Therefore cystine stones can be more effectively treated with direct chemolysis using disulfide exchange resins. Calcium stones are the least amenable to chemolysis, but some success had been shown with EDTA chelation; however, toxicity to the urothelium limits the usefulness of this approach.

Chemotherapy and immunotherapy for upper tract transitional cell carcinoma (see also Chapter 28)

Nephroureterectomy with excision of a bladder cuff is the gold standard of care for upper tract TCC. Organ-preserving procedures that include ureteroscopic or percutaneous resection and segmental ureterectomy have been reserved typically for patients with solitary kidney, bilateral disease, poor renal function, small tumor burden, and low-grade disease [70]. The advent of improved endourologic techniques facilitates access to any part of the upper tract so that tumor location is no longer a limiting factor. Adjuvant topical immunotherapy or chemotherapy post endoscopic resection of upper tract TCC has been used in an attempt to reduce the risk of recurrence and progression. Bacillus Calmette-Guérin (BCG), mitomycin-C (MMC), and thiotepa are the most common agents used.

There are several important considerations when using a topical chemotherapeutic agent as compared to a chemolytic or antifungal agent. In terms of mode of instillation, the antegrade approach has been hypothesized to maximize contact between the agent and the urothelium, and minimize contact interference between the agent and retrograde ureteral stent [71]. However, this approach predisposes the patient to the theoretical risk of nephrostomy tract seeding. Nevertheless, there are no available data to advocate one approach over another [72]. High pressures in the renal pelvis and extravasation after BCG application must be avoided. For the antegrade approach, the patency of the ureter to the bladder must be verified before each perfusion using contrast. This also excludes any pyelovenous or pyelolymphatic backflow. If the nephrostomy tract was used for resection of the upper tract TCC, initiation of adjuvant BCG therapy is usually delayed for 2–3 weeks to allow for healing of the urothelium, thereby decreasing the risk of systemic side effects. Furthermore, BCG must not be instilled in the presence of gross hematuria for fear of severe systemic complications.

Oosterlinka *et al*. described a method to instill BCG in an antegrade fashion into the upper tract. A dose of 360 mg Immuno BCG Pasteur F (Institut Pasteur, Paris, France) or 243 mg Immucyst (Sanofi Winthrop, Meyriez, Switzerland) is dissolved in 150 mL of normal saline. This is the same concentration but three times the dose and volume that is used intravesically. The flask is placed 20 cm above the level of the kidney of the supine patient. A continuous flow of approximately 1 mL/min (15–20 drops/min) is maintained for 2 h [73]. After the perfusion is finished, the nephrostomy tube is clamped. Patients receive ampicillin prophylactically and are kept under hospital surveillance for one night. BCG instillations are repeated on a weekly basis for 6 weeks [74].

For the retrograde approach, it is advised not to use ureteral catheters larger than 5F to allow drainage along the ureteral catheter to the bladder. It is very helpful to use fluoroscopy, at least for the first session, to establish proper catheter position and rule out unexpected anatomic difficulties. Free flow of urine from the catheter or retrograde injection of contrast verifies proper position in the collecting system. Ureteral catheters are secured via silk ties to a Foley catheter placed to drain the bladder and brought to rest at the bladder neck. The Foley catheter is either left to straight drainage or elevated over the bedrail to allow some collection into the bladder, depending on whether simultaneous bladder exposure is desired. It may also be capped during treatment if formal intravesical instillation is performed at the same time. The viscosity of the full-dose BCG suspension is such that it will not spontaneously drip under gravity instillation through such a small 4F catheter. Therefore, low-dose BCG (one-third to one-tenth standard dose) plus interferon-α (50–100 million units) in 50 mL normal saline is used with the retrograde approach [70]. The patient is positioned supine and the medication is suspended in an intravenous bag no more than 30 cm above the kidney level. Medication is instilled via microdrip tubing at the rate of one drop per 2 s, corresponding to a rate of approximately 30 mL/h. The drug is only instilled via gravity and should never be placed on a pump for fear of increased intrarenal pressure. At the end of treatment, the Foley catheter is drained and then removed with the attached ureteral catheters.

Table 26.4 Studies evaluating topical therapy for upper tract urothelial cancer (adapted from Rastinehad *et al.* [102]).

Study	Indication	Number of patients (renal units)	Therapy	Mean follow-up (months)	Comments
Jarret *et al.* [91]	Adjuvant to percutaneous treatment	17 (19)	BCG	55	No significant improvement in survival with BCG
Elliott *et al.* [92]	Adjuvant to endoscopy	18	Thiotepa, MMC, BCG	N/A	No difference in outcome between treated and untreated
Yokogi *et al.* [93]	CIS	5 (8)	BCG	10–46	NED in 5/8 renal units
Martinez-Pineiro *et al.* [94]	Adjuvant to endoscopy	32 (36)	BCG, MMC, thiotepa, IFN-α	30.7	12.5% recurrence with BCG, 14.2% with MMC, 60% with thiotepa; no significant findings with IFN-α
Keeley and Bagley [108]	Adjuvant to ureteroscopy	19 (21)	MMC	30	35% complete response; 27% partial response, and 38% no response
Patel and Fuchs [95]	Adjuvant to ureteroscopy	13 (17)	BCG	14.6	NED in 15/17 renal units
Nishino *et al.* [96]	CIS	6 (8)	BCG	22	NED in 8/8 renal units
Nonomura *et al.* [97]	CIS	11	BCG	NA	NED in 7/11 patients
Chen *et al.* [98]	–	15 (23)	BCG/IFN-α	15.3	70% response rate (74% for CIS)
Miyake *et al.* [99]	CIS	16	BCG	30	NED in 13/16 patients
Thalmann *et al.* [71]	Not eligible for open surgery	37 (41)	BCG	42	87% recurred or progressed; 32% CIS disease-free
Palou *et al.* [100]	Adjuvant to percutaneous treatment	19	BCG in 14, MMC in 5	51	57.9% recurrence in treated patients vs 26.7% in untreated patients
Katz *et al.* [101]	CIS, adjuvant to endoscopy	10 (11)	BCG–IFN-α	24	80% complete response, 20% partial response
Rastinehad *et al.* [102]	Adjuvant to endoscopy	(50)	BCG	80.8	No statistical significance between any of the treated and nontreated groups

A novel approach to gain upper tract BCG exposure was reported by Herr in a patient with grade 3 renal pelvic TCC and carcinoma *in situ* (CIS) in an ectopic solitary kidney [75]. After open surgical resection, a freely refluxing pyelovesical anastomosis was constructed. The patient received six weekly installations of BCG and remained recurrence free at 13 months follow-up. Ramsey and Soloway reported a similar approach accomplished by creating a freely refluxing system after autotransplantation of a solitary kidney with recurrent pyelocalyceal TCC [76]. For patients with refluxing urinary diversions, MMC or BCG can be delivered via a catheter placed into the conduit or reservoir.

A substantial proportion of patients with endoscopically managed upper tract TCC will develop a recurrence. Adjuvant topical immunotherapy or chemotherapies have been used in an attempt to reduce the risk of tumor recurrence and are often reserved for patients with large, multifocal, or residual tumor. The true benefit of topical therapy, either as a primary treatment for CIS or as adjuvant therapy for endoscopically treated upper tract TCC, is difficult to assess due to the heterogeneous groups of patients receiving such therapy (solitary vs multifocal disease, primary vs recurrent, low vs high grade) [70]. These retrospective case series are summarized in Table 26.4. Here we discuss the three most common agents used.

Bacillus Calmette-Guérin

BCG, a live attenuated strain of *Mycobacterium bovis*, first indicated as a tuberculosis vaccine, has had widespread use in intravesical immunotherapy since the 1970s [77]. It has since become the drug of choice for treatment of CIS, in addition to being an effective prophylactic agent against recurrences following transurethral resection of high-grade superficial bladder tumor [78–80].

The mechanism of action has been intensively investigated. It binds directly to fibronectin within the urothelium, leading to direct stimulation of cell-based immunologic response. Numerous cytokines involved in the initiation or maintenance of inflammatory processes, including tumor necrosis factor-α, granulocyte–macrophage colony-stimulating factor, interferon (IFN)-γ, and interleukins are induced. This immunologic response activates cell-mediated cytotoxic mechanisms that are believed to underlie the efficacy of BCG in the prevention of recurrence and progression [81].

Most patients develop an inflammatory immunologic response to BCG during a typical induction course of six weekly instillations. Optimal dosing and instillation schedules have not yet been established, but some trials have demonstrated that a reduced dosing regimen (one-third dose) may be as effective as standard dosing but with fewer side effects [82–84]. Studer *et al*. first demonstrated the feasibility and efficacy of using BCG in the upper urinary tract [74]. They treated 10 renal units that had cytologic evidence for CIS with BCG delivered via a percutaneous nephrostomy tube. In seven of the 10 renal units, urinary cytology reverted to negative. Though complications were few, BCG sepsis did develop in one patient, necessitating cessation of therapy. Since then, several studies have demonstrated the safety and efficacy of intracavitary topical therapy in combination with endoscopic management in upper tract TCC (Table 26.4) [71, 85–102].

There have been no randomized trials comparing endoscopic treatment of upper tract TCC with or without BCG. In one of the largest series of adjuvant therapy for upper tract TCC, Thalmann *et al.* retrospectively evaluated the results of BCG therapy in patients not eligible for nephroureterectomy [71]. Thirty-seven patients (22 with CIS, 15 with Ta or higher after endoscopic resection) were treated with six weekly perfusions of BCG via a 10F nephrostomy tube. At a median follow-up of 42 months, 14 patients (38%) died of urothelial cancer, 11 (29%) of other causes, and 12 (33%) were alive. Other adverse outcomes included severe septicemia in two patients. There was no seeding of the nephrostomy tube tract and dialysis was avoided. Overall median survival was 42 months (range 1–137 months) with median recurrence-free survival of 21 months (range 1–137 months). The authors noted that this was a patient population with a poor prognosis, and while BCG extended survival for some patients, it did not provide cure except for in some patients with CIS. Of the patients treated in the adjuvant setting for papillary disease, only 13% remained without recurrent or progressive disease, with a median time to recurrence of 10 months. In contrast, treatment of CIS resulted in 32% of renal units remaining disease free for a median follow-up of 51 months. Results achieved with intracavitary topical therapy have been varied.

Some authors have found intracavitary topical therapy to be beneficial in terms of recurrence and disease-free survival, but not overall survival. Orihuela and Smith found a recurrence rate of 80% among patients who did not receive supplemental BCG versus a recurrence rate of 16.6% among those who did [86]. However, an update of their series could not ultimately demonstrate a survival advantage with the addition of adjuvant BCG [91]. Martinez-Pineiro *et al*. have shown an advantage of adding BCG or MMC after endoscopic treatment of upper tract TCC [94]. These authors reported a recurrence rate of 50% among patients with grade 2 or 3 disease who were not treated with adjuvant therapy versus 27.7% among a similar group of patients who received some form of adjuvant therapy. The authors used several drugs, including BCG, MMC, 5-fluorouracil, thiotepa, and interferon-α, but only BCG and MMC were promising. Katz *et al*. published their initial experience with BCG plus IFN-α2b [101]. With a median follow-up of 24 months, 80% of patients demonstrated a complete response, while 20% had a partial response (decrease in tumor size, number, or both). The authors reported that the treatment was well-tolerated in the office setting and did not note any complications.

In contrast, other studies have not shown a significant difference between patients treated with adjuvant MMC or BCG compared to those undergoing endoscopic treatment alone [92, 103]. Hayashida *et al*. reported a 50% disease recurrence rate at a follow-up of 50.9 months after intrarenal perfusion of BCG with endoscopic treatment [104]. This high recurrence rate occurred despite an initial return of cytology results to normal and all of these patients suffered cancer-specific mortality. Rastinehad *et al*. retrospectively studied 133 renal units treated by percutaneous resection for upper tract TCC [102]. Eighty-nine renal units treated primarily by percutaneous resection were then analyzed. Fifty renal units received adjuvant BCG therapy 2 weeks after endoscopic management for a total of six courses. Recurrence was defined as a positive biopsy result after the third-look nephroscopy. Overall median follow-up was 40.8 months. There was no statistical difference with regard to tumor grade or stage between treated and nontreated groups. Recurrence, time to recurrence, and progression of disease among renal units treated with BCG were subselected by grade and compared with the corresponding nontreated group. There was no statistical significance demonstrated between any of the treated and nontreated groups. The authors concluded that there is no overall oncologic benefit in the administration of adjuvant BCG with regard to disease recurrence, interval to recurrence, and progression of disease in the treatment of upper tract TCC.

There are several known complications of cavitary BCG therapy. Persistent fever after BCG administration has been reported in three of 59 (5.1%) patients in a combined series, though this resolved in all cases with appropriate antimicrobial therapy [91, 94, 103]. Granulomatous involvement of the upper urinary tract may occur in up to 25% of patients after BCG administration; however, the significance of these findings is not yet clear [105].

The controversy and variability among studies addressing the intracavitary topical use of BCG is likely the result of nonrandomization and the bias in patient selection for this modality of treatment. Some authors treat all patients with adjuvant therapy while others treat only high-risk patients. Furthermore, it is important to note that several products contain different substrains of BCG. There is variability of BCG organisms per milligram of vaccine with different substrains and from lot to lot within the same substrain [106, 107]. Thus, the true efficacy of adjuvant BCG therapy for upper tract TCC has yet to be adequately evaluated. However, secondary effects of therapy seem to be generally well-tolerated among patients.

Mitomycin-C

Less information is available on the use of intracavitary MMC topical treatment compared with BCG. MMC is a 334-kDa alkylating agent that inhibits DNA synthesis. Because of its moderately high molecular weight, there are few problems with transurothelial absorption. Therefore, side effects such as myelosuppression are rare. The typical dosage varies from 20 to 60 mg per instillation, and the most commonly used dose is 40 mg in 40 mL of saline or sterile water administered weekly for 8 weeks.

Keeley and Bagley reported on adjuvant MMC (40 mg in three divided doses via ureteral catheter) in 19 patients (21 renal units) for high volume, recurrent, or multifocal urothelial carcinoma [108]. No systemic side effects occurred during or after treatment with MMC. Thirty-five percent had a complete response, 27% a partial response (reduction in tumor size >50%), and 38% no response. Tumors with a complete response were of similar size and grade as those that did not respond as well. After a mean follow-up of 30 months, none of the patients suffered local disease progression or died of the disease; however, nearly all the patients required repeat ureteroscopic treatment for residual or recurrent disease. At least one case of toxic agranulocytosis has been reported following absorption of extravasated MMC [94].

An alternative experimental treatment regimen for upper tract TCC in refractory patients is sequential gemcitabine and MMC. The medication dosage is 1 g gemcitabine in 50 mL phosphate-buffered normal saline, then 40 mg MMC in 40 mL of sterile water. The gemcitabine is instilled, followed immediately by the MMC. In a group of patients with treatment-refractory nonmuscle invasive bladder cancer, eight of 37 had upper tract involvement. Gemcitabine alone was effective in only one of 14 patients (7%), while sequential treatment with gemcitabine followed by MMC was successful in 13 of 23 patients (57%) [109]. The rationale for sequential treatment is that gemcitabine is too acidic and will affect MMC activity if the two are given together. Additionally, gemcitabine primarily kills cells undergoing DNA synthesis (S-phase), while MMC is noncell phase-specific and leads to cell cycle arrest. Gemcitabine is given first, followed by MMC to maximize therapeutic efficacy. Some authors consider that outcome can be improved by overnight fasting, use of sodium bicarbonate to reduce drug degradation, and an increased concentration of gemcitabine to 40 mg in 20 mL [110].

Thiotepa

Thiotepa (triethylenethiophosphoramide) is an alkylating agent and is not cell-cycle specific. Introduced in 1961, thiotepa is the oldest and one of the least expensive intravesical drugs. Doses range from 30 to 60 mg in 30–60 mL of sterile water or saline. The lower dose appeared to be as effective as the higher one in a comparative study when the concentrations were the same [111]. The Medical Research Council Working Party on Urological Cancer reported that the lower concentration of 30 mg in 50 mL was not effective [112]. The usual regimen consists of six to eight weekly instillations. A low molecular weight of 189 kDa allows partial absorption through the urothelium with possible systemic toxicity. Myelosuppression is a risk, especially with the 60 mg dose. Complete blood count is obtained before each instillation and treatment is delayed if necessary. Thiotepa has not been as well-evaluated as many other topical agents as adjuvant therapy after endoscopic management of upper tract TCC [92, 94].

Summary

Although the cumulative experience appears encouraging regarding the efficacy of topical immunotherapy, especially against CIS, no individual study has shown statistical improvement in terms of survival and recurrence rates. This could be the result of insufficient numbers of patients to examine the clinical significance of the drugs and delivery of inadequate drug concentrations over an appropriate period of time to enable a clinical response when compared with lower tract TCC [7]. There is no doubt that further studies are required to settle this issue. It is apparent that most published series regarding percutaneous adjuvant therapy involve few patients with short follow-up, making it difficult to reach any meaningful conclusion. No protocol of treatment has as yet been accepted. None of the published series has evaluated the role of maintenance therapy, likely because of access problems. Randomized multicenter trials are needed to evaluate the role of adjuvant topical therapy. Intracavitary therapy is a worthwhile therapeutic option for conservative noninvasive upper tract TCC with acceptable side effects. For this reason it may be included in the routine urologic armamentarium.

Antifungal therapy

Upper urinary tract fungal infections are rare and are usually associated with diabetes, chronic renal failure, long-term antibiotic usage, immunosuppressants, and terminal malignancy. Diagnosis is based on microscopic examination of urine and specific fungal culture. Histopathologic examination of fungal balls (accretions) will demonstrate the fungus. The polymerase chain reaction has been used to detect candidemia in patients with candiduria, before the culture reports are available [113, 114]. Opportunistic pathogens, such as *Candida*, *Aspergillus*, *Mucor*, *Cryptococcus*, and *Histoplasma*, in particular are known to infect the kidneys in predisposed individuals with serious complications. These infections are often insidious and their diagnosis is usually delayed because of the coexisting illnesses [115, 116]. Renal involvement by fungi has been found to be associated with increased morbidity and mortality, particularly in cases of infections by angioinvasive fungi such as *Aspergillus* and *Mucor* [117–119].

Fungal infection may be systemic with secondary involvement of the urinary system, or it may originate in the urinary tract and then disseminate hematogenously. The use of an indwelling urethral catheter and administration of multiple antibiotics increases the risk of dissemination of urinary fungal infections [120]. These infections of the urinary tract must be diagnosed quickly and treated aggressively. If these infections are improperly treated, they can cause urinary obstruction through formation of fungal balls [121–123]. These fungal balls cause hydronephrosis, oliguria or even anuria, destruction of renal parenchyma, widespread dissemination of the organism, and death of the patient [124].

Percutaneous antifungal irrigation permits administration of highly toxic antifungal drugs to patients with localized infection, thereby minimizing systemic side effects [125, 126]. Systemic antifungal agents have been successfully used, but in the presence of an obstructed kidney due to extensive fungal infection, drainage of the pelvicalyceal system is mandatory to salvage the kidney. Amphotericin B and its formulations, the azoles (fluconazole, itraconazole, voriconazole, and ketoconazole), caspofungin, and flucytosine are used to treat urinary fungal infections. Schelenz and Ross reported that the intravenous antifungal drugs, such as caspofungin or amphotericin B, are useful in treating or preventing candidemia during instrumentation, such as insertion of nephrostomy tubes in cases of *Candida* pyonephrosis [2]. However, they are unlikely to lead to cure if used as the sole treatment. Conservative management should also include local drainage of pus and fungi as well as instillation of an effective antifungal agent.

The discussion below is limited to the major drugs used as topical urinary antifungals, namely fluconazole and amphotericin B. It must be kept in mind that fungal infections involving the genitourinary tract are frequently part of a multiorgan systemic disease in an immunocompromised host.

Fluconazole

Fluconazole is a triazole antifungal agent that is less toxic and more efficient than other imidazole members, and it is safe in infants and children. The drug inhibits the cytochrome P-450 enzyme responsible for conversion of lanosterol to ergosterol, the major sterol of most fungal cell membranes. Fluconazole is highly water soluble and can be administered intravenously or orally. It is cleared primarily by renal excretion, with approximately 80% of the dose excreted as unchanged drug [127]. Fluconazole administered by mouth or intravenously achieves high urine levels [128]. Generally, the drug is safe and well tolerated, even in very large doses. The most common adverse reactions are gastrointestinal disturbances.

Systemic fluconazole therapy can be effective in treating candiduria. In one series, orally administered fluconazole (100 mg twice daily for 10 days) eradicated candiduria in 19 of 20 critically ill patients, which was comparable to amphotericin B bladder irrigations [129, 130]. It is important to note that an elevated serum creatinine value is associated with a reduced rate of fungal eradication from the urine with systemic fluconazole therapy. This is likely related to lower urinary levels of fluconazole in patients with reduced renal function [131]. Therefore, in patients with renal impairment, direct irrigation may be more effective at treating candiduria.

Fluconazole has been reported as an effective antifungal bladder irrigant [132]. Percutaneous fluconazole irrigation was successfully used to treat candidiasis in nephrostomy tubes that was unresponsive to systemic intravenous treatment [126]. Fluconazole solution was used as an antifungal irrigant in 20 patients with a nephrostomy tube or suprapubic catheter who presented with two positive urine cultures for *Candida*. In 17 (85%) patients, *Candida* was eradicated from the urine by the third to sixth day of irrigation. No side effects were noted [133].

Amphotericin B

Amphotericin B was first isolated as a by-product resulting from the fermentation process of *Streptomyces nodosus* and is a member of the polyene macrolide class of antibiotics [134]. Depending on the drug concentration and susceptibility of the organism, amphotericin B may be either fungistatic or fungicidal. It binds to the sterol ergosterol that is present in the cell wall of susceptible fungi, leading to an alteration in cell wall permeability, thereby causing leakage of cell components and subsequent cell death. Oxidation-dependent amphotericin B-induced stimulation of macrophages of the host cells also may contribute to its antifungal properties [135]. Amphotericin B deoxycholate has been used in the treatment of most fungal infections, with nephrotoxicity being the most common serious chronic adverse effect[136]. Fortunately, this azotemia is usually reversible and sodium loading with intravenous saline and hydration may prevent or reduce the severity of the nephrotoxicity.

In an effort to reduce systemic side effects, new formulations of amphotericin B have been developed. These encapsulate amphotericin B in lipid vehicles which are taken up by the reticuloendothelial system concentrated in liposomes. Monocytes/macrophages in the peripheral blood are thought to take up the drug-laden liposomes and move them to the site of infection, where free active drug is thought to be released through the action of phospholipases [127].

Bladder irrigation with amphotericin B is widely used and has become a standard treatment, although it has not undergone controlled trials [134, 137–141]. Tuon *et al*. found that amphotericin B bladder irrigation (ABBI) showed a higher clearance of the candiduria 24 h after the end of therapy than fluconazole [142]. This was confirmed by fungal culture 5 days after the end of both therapies. The evaluation of ABBI using an intermittent or continuous system of delivery showed an early candiduria clearance (24 h after therapy) of 80% and 82%, respectively. The use of continuous ABBI for more than 5 days showed a better result (88% vs 78%, respectively), but this was not statistically significant. Although ABBI has been used in clinical practice, its use is not standardized, and some authors question whether amphotericin B bladder irrigations have any diagnostic or therapeutic value [143]. Others have advocated that amphotericin B no longer be used in the management of candiduria [129]. Removal of the urinary catheter, if possible, is more beneficial for the patient than instillation of bladder irrigation with amphotericin B [144].

In cases of pyonephrosis, the insertion of percutaneous nephrostomy (PCN) for direct irrigation allows urinary diversion with subsequent improvement in renal function, and enables the local administration of an antifungal drug directly to the site of infection [145]. Schelenz and Ross demonstrated the limitation of intravenous antifungal agents such as caspofungin as the sole treatment of an obstructive upper urinary tract infection due to *Candida* species [2]. In order to achieve long–term sustained cure from an obstructive pyonephrosis, pus and fungal balls should be drained and an antifungal agent such as amphotericin B deoxycholate instilled locally. An important issue in the management of pyonephrosis caused by such infections is the accumulation of pus and fungi in an obstructed space, the renal pelvices. As with other enclosed bacterial infections such as empyemas, drainage of the pus is of fundamental importance and may explain why systemic treatment with antifungals such as amphotericin B, caspofungin, or fluconazole alone have proven to be unsuccessful [126, 146]. Watson *et al*. reported percutaneous upper urinary tract drainage to be a potentially life-saving adjunct in the treatment of pyonephrosis [147]. Several case studies highlight the advantage of this maneuver in difficult cases involving obstruction due to extensive fungus. Bartone *et al*. reported on five neonates with obstructive urinary tract candidiasis in whom PCN had a major role in management [148]. In another study, eleven PCNs were placed in seven patients (two neonates and five adults), who were identified to have renal fungal infections [145]. PCN allowed prompt microbiologic diagnosis of fungal infection (*Candida albicans* in six patients, *Torulopsis glabrata* in one); urinary diversion with subsequent improvement in renal function, enabling systemic administration of the potentially toxic antifungal drugs 5-fluorocytosine and amphotericin B (four patients), local irrigation with amphotericin B (four patients), guidewire fragmentation of fungal balls (two patients); and introduction of a Simpson atherectomy device to obtain biopsy specimens from an obstructing ureteral polypoid lesion (one patient). Untreated or neglected candidiasis may progress to fungal balls or abscess formation. Sonography is commonly used as the initial imaging procedure but retrograde and antegrade pyelographies are used for biopsy, diagnosis, and treatment [149]. The advantages of PCN in this setting include prompt drainage of the obstruction, direct access to obtain specimens from the renal pelvis to confirm the diagnosis, direct irrigation of the fungal balls with amphotericin B, and an access route for fragmentation of fungal balls by guidewire manipulation [145]. Placement of PCN with antegrade amphotericin B irrigation, coupled with systemic antifungal therapy, is the mainstay of treatment for pyonephrosis.

Streptokinase has also been used in conjunction with amphotericin B in the treatment of pyonephrosis. Hutton reported a problematic case of a very low birthweight infant with obstructing ureteropelvic junction fungal balls that were refractory to standard measures of adequate PCN drainage, pelvic irrigation with amphotericin B, and systemic antifungal treatment [150]. In an attempt to avoid potentially difficult open surgery, the author used streptokinase solution (3000 IU/mL) for irrigation. This was successful in clearing the fungal balls, relieving obstruction, and rendering the urine sterile, and highlights the potential role for streptokinase in cases of renal candidiasis refractory to current treatment protocols.

The role of antifungal agents for upper tract fungal infections will require ongoing investigation. However, the relative rarity of this condition may preclude randomized trials. In cases of pyonephrosis the most reported approaches would include placement of a nephrostomy tube and local instillation of an antifungal agent such as amphotericin B. The advantage of topical intracavitary treatment is that highly toxic medications can be delivered to the site of infection rather than systemically, which can minimize potential side effects.

Conclusions

Percutaneous therapy delivers medications or chemotherapeutics directly into the collecting system and can be highly effective at targeting the pathology. Direst therapy allows high local concentrations to be delivered while avoiding potential systemic complications. Stone dissolution through chemolysis remains an option for urologists even in the advent of more sophisticated modalities in the treatment of urolithiasis. Direct chemolysis is most useful for cystine and struvite stones. Chemolysis is also appropriate for the treatment of uric acid stones when medical therapy is not feasible, e.g. in a patient who is noncompliant or cannot tolerate oral sodium or potassium salts. There is no clinically useful irrigant for dissolving calcium oxalate calculi. Chemolytic solutions may be used as primary therapy or as adjuncts to either ESWL or PCNL.

Intracavitary immunotherapy/chemotherapy is a useful adjuvant therapy post endoscopic management of noninvasive upper tract TCC with acceptable side effects but no individual study has shown statistical improvement in terms of survival or recurrence.

Percutaneous instillation of topical antifungal agents such as amphoteracin B permits administration of highly toxic antifungal drugs to patients with localized infection, thereby minimizing systemic side effects.

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CHAPTER 27

Percutaneous Treatment of Ureteropelvic Junction Obstruction

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Introduction

Percutaneous endopyelotomy was one of the first minimally invasive surgical procedures to address a reconstructive operation. In ureteropelvic junction obstruction (UPJO), the ultimate goal remains the relief of the obstruction in order to preserve renal function, with minimal morbidity. Percutaneous endopyelotomy rapidly gained acceptance and became widely acclaimed as a new gold standard in the management of UPJO, replacing open pyeloplasty [1].

However, being totally *endo*scopic, endopyelotomy can only address intrinsic factors of obstruction; extrinsic causes cannot be corrected. In UPJO, the renal pelvis is usually dilated or redundant. Classically the volume should be reduced by resecting part of the wall, but this will not be possible with a purely endoscopic procedure, neither redundancy of the renal pelvis. This probably explains its inferior success rate compared to pyeloplasty, especially when it is applied without selection [2–5]. Similarly to many pioneering techniques, it has been superseded by newer techniques and is now less often performed (see Patient selection below) [6–8]. It nevertheless retains its status as a landmark procedure, and could be regarded as one of the first natural orifice transluminal endoscopic surgeries (NOTES) to be routinely performed [7].

Preoperative management

Preoperative evaluation of UPJO is mandatory, with a view to documenting the following critical prognostic factors: the stricture (length, nature, and degree), the involved renoureteral unit (individual renal function, degree of hydronephrosis, remaining ureter), the presence of extrinsic factors (crossing vessels, bands), and the patient themselves (Table 27.1).

Preoperative drainage

Preoperative decompression of the collecting system is advisable in totally obstructed cases, in case of active infection, or when there is a need to evaluate the function of the kidney. Tubular function recuperates in 10–15 days; glomerular function improves more slowly (over up to 3 months). Despite its potential associated morbidity, we favor a small nephrostomy tube inserted under local anesthesia rather than a double-J stent, which commonly induces an inflammatory reaction at the UPJ that may later interfere with healing.

Antegrade endopyelotomy

Percutaneous endopyelotomy (Figure 27.1)

A retrograde open-end ureteral catheter is inserted and advanced through the UPJ. If this maneuver fails, the endoscopic route should be abandoned, since further attempts to localize an impassable UPJ usually are unsuccessful, and an unguided incision is dangerous and may result in total separation of the ureter.

Percutaneous endopyelotomy can be performed with the patient already in the prone position using a flexible cystoscope; otherwise the patient is repositioned on the

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Table 27.1 Preoperative evaluation.

Stricture	Length
	Nature
	Degree
Renoureteric unit	Renal function
	Degree of hydronephrosis
	Remaining ureter
Extrinsic factors	Crossing vessels
	Bands, adhesions
Patient	General risk factors
	Habitus
	Informed of procedure and its follow-up

table as for a classical percutaneous procedure, and a posterior calyx is punctured and catheterized. A middle or superior calyx should be selected to secure an adequate working angle on the UPJ. The tract is dilated and the nephroscope is introduced. Secondary calculi are extracted at this stage. The UPJ is easily identified by the protruding retrograde ureteral catheter and a second guidewire is introduced from above and down into the ureter (Figure 27.1A). The best orientation of the incision is still a matter of debate; we prefer to make the incision posterolaterally through the entire thickness of the pelvic wall, the UPJ, and the narrow portion of the proximal ureter, and as far down as necessary to visualize a normal caliber lumen, essentially performing an endoureteropyelotomy. A significant advantage of the direct percutaneous approach is the possibility of careful visual inspection of the pelvic wall, looking for pulsation transmitted from significant adjacent crossing vessels.

The second guidewire is advantageous to straighten and stiffen the ureter to be incised: the cold knife is railroaded on the track (Figure 27.1B and C). The specific characteristics of the knife (straight or hooked knife, scissors, etc. have little importance; equal success has been obtained with laser or electric incision (aggressive coagulation is unwarranted). When the exact length of the abnormal ureter is in doubt, a dilation balloon is inserted over the second guidewire and is inflated with contrast under fluoroscopic control, care being taken to correct any residual or additional narrowed areas (Figure 27.1D).

Prolonged stenting and drainage are deemed essential, although their exact duration is still a matter of controversy. A convenient drainage system consists of a 14/7 double-J stent straddling the incised UPJ; other drainage techniques can be used successfully, provided that extravasation is minimal and drainage is adequate. We usually leave a small nephrostomy tube in place for a few days. The internal stent is removed under local anesthesia in the outpatient clinic after 6 weeks [1, 9, 10].

Invagination technique (Figure 27.2)

A safe UPJ incision may be facilitated by the modified technique described by Gelet of Lyon, France. Instead of using a simple open-ended ureteral catheter for the initial retrograde UPJ catheterization, a dilation balloon is used and inflated below the UPJ (Figure 27.2A). After percutaneous access has been obtained, the inflated balloon is grasped from above and pulled inside the renal pelvis, invaginating the UPJ and proximal ureter (Figure 27.2B). Using the holmium laser or a small electrocautery electrode, the double tissue layer (pelvis and ureter) is incised from inside the renal pelvis, down to the plastic balloon (Figure 27.2C). If residual or additional narrowing is suspected, the balloon is reinflated on its way out to calibrate the ureter. When the balloon is deflated and removed from below, spontaneous reduction of the invagination occurs. Drainage and stenting are as in the procedure described above.

The invagination technique allows easier incision of the UPJ as the tissue is stabilized on the dilated balloon. It also reduces the risk of damaging crossing vessels, although such complications have occurred [11].

Endopyeloplasty

This ingenious procedure is a combination of endopyelotomy and pyeloplasty. Using a custom-made suturing device, a standard vertical endopyelotomy incision is sutured transversely (Heinecke–Miculikz principle). Its primary aim is healing of the endopyelotomy incision by accurate suturing, minimizing fibrosis by avoiding urinary extravasation. Preliminary results for this non-dismembered procedure appear promising. A totally dismembered procedure using the same suturing technique has been investigated. Unfortunately, the original series has not been duplicated, and to our knowledge endopyeloplasty is rarely performed [12, 13].

Retrograde endopyelotomy

In order to further reduce the morbidity of the procedure, purely retrograde approaches have been devised. They share the advantage of avoiding a percutaneous nephrostomy, but they do not allow careful regional inspection for pulsation of crossing vessels, or the direct visual control necessary for an exact incision [10].

Ureterorenoscopic approach

A small caliber ureterorenoscope is advanced up to the level of the UPJ and a posterolateral incision is performed under direct vision. The procedure is

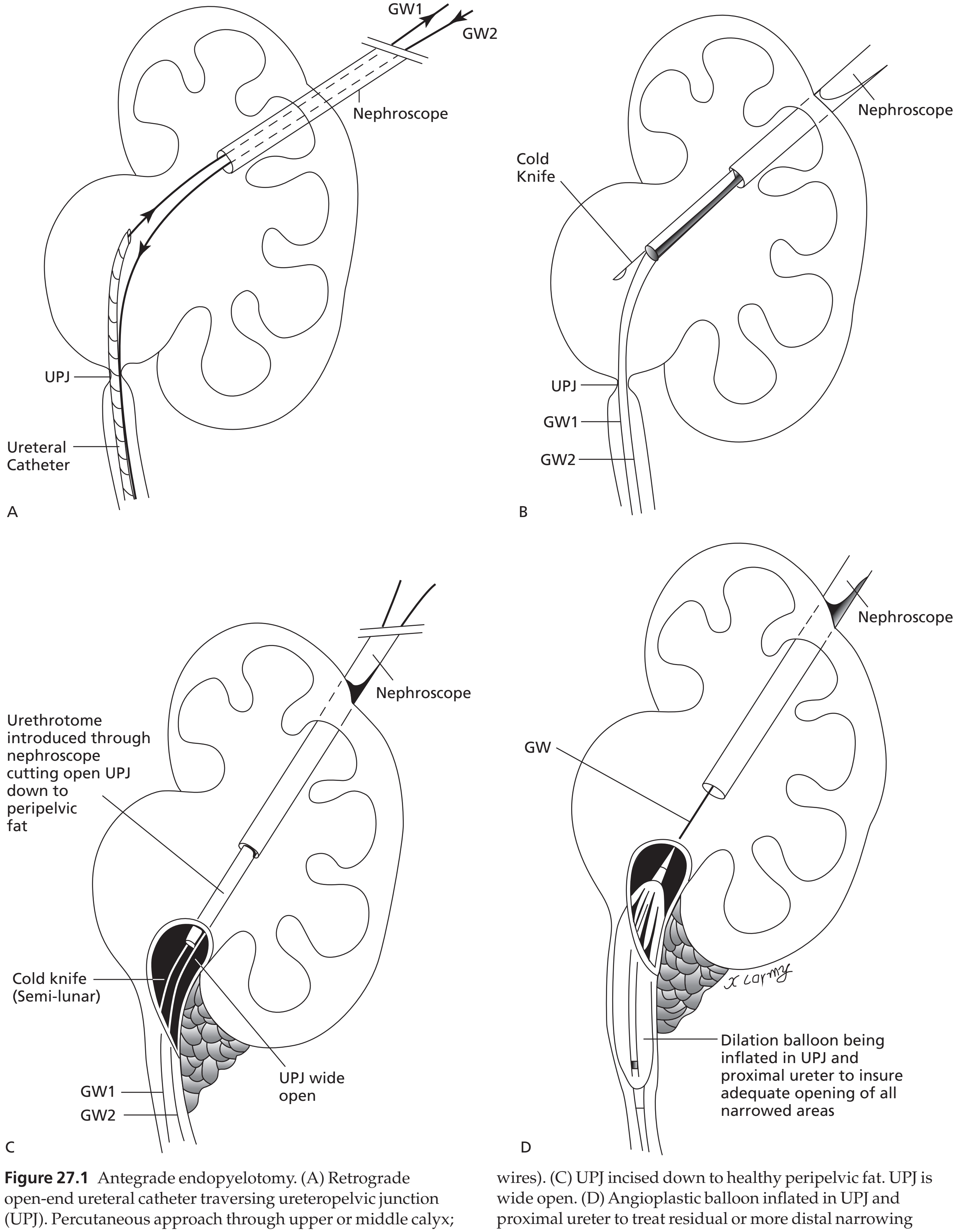
GW1
GW2
Nephroscope
UPJ
Ureteral Catheter
A
Nephroscope
Cold Knife
UPJ
GW1
GW2
B
Nephroscope
Urethrotome introduced through nephroscope cutting open UPJ down to peripelvic fat
Cold knife (Semi-lunar)
UPJ wide open
GW1
GW2
C
Nephroscope
GW
X Cormy
Dilation balloon being inflated in UPJ and proximal ureter to insure adequate opening of all narrowed areas
D

Figure 27.1 Antegrade endopyelotomy. (A) Retrograde open-end ureteral catheter traversing ureteropelvic junction (UPJ). Percutaneous approach through upper or middle calyx; second guidewire (GW) from above, down the ureter. (B) Knife through nephroscope (cutting blade railroaded by the two wires). (C) UPJ incised down to healthy peripelvic fat. UPJ is wide open. (D) Angioplastic balloon inflated in UPJ and proximal ureter to treat residual or more distal narrowing (reproduced from Van Cangh and Nesa. Endoureteropyelotomy. In: *Atlas Urol Clin North Am* 1996;4(1)).

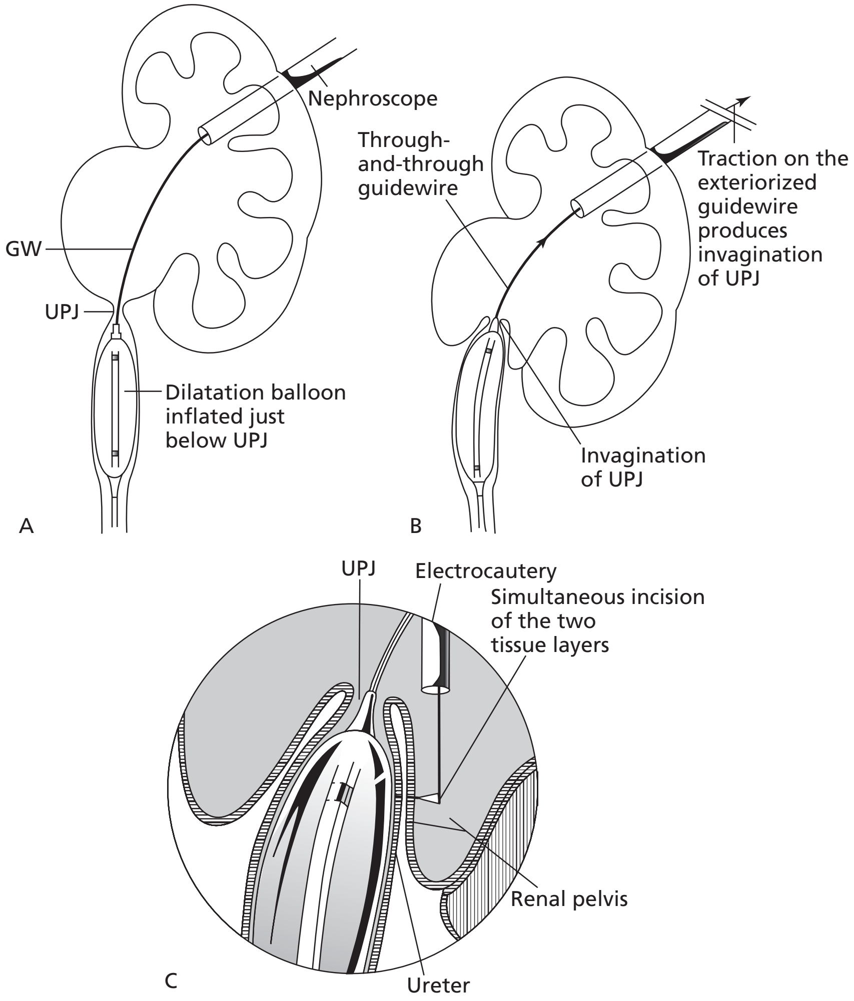
Nephroscope
GW
UPJ
Dilatation balloon inflated just below UPJ
A
Through-and-through guidewire
Traction on the exteriorized guidewire produces invagination of UPJ
Invagination of UPJ
B
UPJ
Electrocautery
Simultaneous incision of the two tissue layers
Renal pelvis
Ureter
C

Figure 27.2 Invagination technique. (A) Dilation balloon inserted and inflated below ureteropelvic junction (UPJ). (B) Cranial traction on the exteriorized wire invaginates ureter into renal pelvis. (C) Close–up view of invaginated UPJ: laser or electrocautery incision of the double tissue layer, GW, guidewire (reproduced from Van Cangh and Nesa. Endoureteropyelotomy. In: *Atlas Urol Clin North Am* 1996;4(1)).

facilitated by the preliminary insertion of a double -J stent, which then remains in place for 8–10 days; this maneuver however, adds to the complexity of this technically difficult procedure, especially in muscular male patients. Most authors recommend the use of the flexible ureterorenoscope combined with the holmium laser.

Balloon dilation and rupture ("endoburst")

A retrograde ureteropyelogram delineates the upper collecting system. An angioplasty balloon is inserted over a guidewire and positioned across the UPJ under fluoroscopic control. The balloon is inflated until wasting completely disappears. Several inflation/deflection cycles are recommended in order to ensure that no residual narrowing remains. An endopyelotomy stent is inserted over the initial guidewire. With few exceptions, long-term success with this technique has been inferior to that with incisional techniques.

Balloon electrocautery incision: Acucise® endopyelotomy

The Acucise device is a 6F catheter driving a 10/24F low-pressure balloon fitted with an electrosurgical wire active over the 3-cm expendable portion of the balloon. The operative technique is similar to the one described immediately above, except that the UPJ is not forcefully disrupted but cleanly cut by the electrosurgical wire that is activated during inflation of the balloon. Extravasation of contrast indicates that the incision has been completed. If there is doubt, flexible ureteroscopy and additional electrosurgical or laser incision under direct vision are recommended. The technique is safe and reliable, especially when the surrounding vascular anatomy of the UPJ has been ascertained by an appropriate imaging study [14].

Laparoscopic pyeloplasty

Laparoscopic pyeloplasty combines the advantages of minimally invasive surgery (reduced morbidity) and of

Table 27.2 Therapeutic options for ureteropelvic junction obstruction.

Open surgery	
Standard	Pyeloplasty
Salvage	Ureterocalycostomy Autotransplantation Transposition of renal vein (right) (Nephrectomy)
Minimally invasive surgery	
Endoscopic Antegrade endopyelotomy Retrograde endopyelotomy	Direct: cold knife, electrocautery, laser Indirect: invagination Direct: ureterorenoscopic Indirect : under fluoroscopic control: • Electroincision with cutting balloon • Dilaceration with angioplastic balloon
Endopyeloplasty	Nondismembered Dismembered (experimental)
Laparoscopic ± robotically assisted	Intraperitoneal Extraperitoneal (Nephrectomy)

open surgery (possibility to correct anatomic factors such as extrinsic obstruction, crossing vessels, and renal pelvis redundancy), and for many has become the new gold standard. Both intraperitoneal and extraperitoneal approaches have been successful in achieving this goal. The recent advance in robotically-assisted procedures, albeit still costly, has increased the interest in this approach, by facilitating the anastomosis. Nevertheless, laparoscopic pyeloplasty remains a difficult procedure, requiring considerable expertise; it is difficult to learn and to teach [7, 15].

Prognostic factors, patient selection, and results (Table 27.2)

Results of endopyelotomy fall somewhat short of contemporary pyeloplasty (67–95% vs 95–100%) [3, 5]. As most endopyelotomy series using different techniques report approximately the same results, it is likely that selection criteria play a major role. Risk factors have been identified: the presence of vessels directly crossing the UPJ stands out as a major prognostic factor of outcome; the degree of hydronephrosis, type of obstruction, and renal function also play a role, although these are of lesser importance. Long avascular strictures and major alteration of renal function clearly contraindicate the procedure.

In our view, now commonly shared but still debated, the presence of significant crossing vessels should be ascertained preoperatively as it significantly influences the outcome. Modern imaging techniques, such as spiral computed tomography (CT), color Doppler, and endoluminal ultrasonography, have replaced the older more invasive procedures. When a significant crossing vessel has been documented, a classical endopyelotomy is likely to provide inferior results, especially in the presence of a large renal pelvis. When a small artery or a venous channel is encountered, consideration can be given to transection of the crossing vessel [9, 10]. If a major vessel is present, an alternative treatment such as open or laparoscopic pyeloplasty is preferable. When renal function is poor (<10%), laparoscopic nephrectomy is the first choice.

Today, the major indications for percutaneous endopyelotomy are the combined treatment of UPJO and concomitant pathology, the most common being secondary renal calculi and secondary UPJO [8]. In addition, several centers with expertise in the procedure continue to recommend the operation in carefully selected patients with primary UPJO.

Conclusions

Percutaneous endopyelotomy stands out as a landmark procedure, opening the way to reconstructive NOTES procedures. Like the majority of pioneering techniques, it has now been superseded by newer developments; it nevertheless retains specific indications, such as secondary UPJO and combined treatment of UPJO and associated anomalies.

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CHAPTER 28

Percutaneous Management of Upper Urinary Tract Transitional Cell Carcinoma

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Introduction

Transitional cell carcinoma (TCC) of the upper urinary tract accounts for approximately 5% of all urothelial carcinoma. Historically, open nephroureterectomy with bladder cuff excision has been the gold standard for treatment of upper urinary tract TCC. With the advent of minimally invasive surgery and laparoscopic procedures, patients have benefitted from smaller incision, shorter hospital stay, reduced pain, and reduced blood loss. Laparoscopic nephroureterectomy has been demonstrated to be feasible with oncologic outcomes that are comparable to open nephroureterectomy [1–3]. However, laparoscopic nephroureterectomy with bladder cuff excision still is an extirpative oncologic surgery in which the renal unit is not spared.

The need for renal preservation in a certain population of patients with upper urinary tract TCC has been recognized, and the endourologic (percutaneous and ureteroscopic) approaches have been employed since the 1980s [4–6]. Tremendous advances in endourologic management of upper urinary tract TCC have been made possible due to modern technology. In particular, modern flexible ureteroscopes provide greater deflection safely to navigate throughout the collecting system, and thoroughly to inspect each calyx for tumor [7–9]. When tumors are found, they are effectively treated with cautery or laser. Current endourologic management for upper urinary tract TCC has been shown to be feasible and a reasonable treatment option without significant compromise of survival of patients when stringent follow-up is planned [10–14].

Patient selection

Nephron-sparing surgery for upper urinary tract TCC emerged from the need to treat patients who would otherwise be anephric and require dialysis under the gold standard surgical approach. For instance, patients with anatomic or functional solitary kidney, renal insufficiency, and bilateral upper urinary tract TCC under the gold standard approach would require dialysis. Moreover, patients with multiple comorbidities often cannot tolerate prolonged general anesthesia and they are precluded from undergoing radical extirpative surgery. The indications for nephron-sparing surgery for upper urinary tract TCC are listed in Table 28.1.

As mentioned, modern flexible ureteroscopes give access to inspect the entire renal collecting system in a retrograde fashion with great success. Since this is accomplished with great accuracy, nephron-sparing endoscopic treatment options have been expanded to include patients with normal contralateral kidney. Patients with low-grade, low-stage tumor of size less than 2 cm that is completely visible and demonstrates no evidence of extension within the ureter or the kidney parenchyma on computed tomography (CT) scan have the option to undergo retrograde endourologic treatment. The results have been acceptable with proper follow-up in these cohorts [14–17]. Thus, the ideal patient for endoscopic management, using the retrograde or percutaneous approach, of upper urinary tract TCC is one with a low-grade and -stage tumor.

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Table 28.1 Absolute indications for nephron-sparing surgery for upper transitional cell carcinoma (TCC).

Solitary kidney (functional or anatomic)
Renal insufficiency
Bilateral upper tract TCC
Multiple comorbidities

Tissue sampling

It is imperative to have accurate diagnoses of the grade and stage of upper urinary tract TCC because these factors influence recurrence, progression, and survival. For example, the recurrence rate for a high-grade TCC is significantly higher than for a low-grade TCC of the upper urinary tract [4]. Similarly, the stage of tumor influences the rate of progression. Superficial lesions (Ta) have a progression rate of 5%, which is much lower than the progression rates of 21% and 50% for T1 and T2 lesions, respectively [18]. Therefore, the higher grade and stage tumors require much more stringent follow-up protocols. Five-year survival rates are much higher for patients with low- -stage upper urinary tract TCC [6].

Percutaneous versus ureteroscopic management

Ureteroscopic treatment can be preferred over the percutaneous approach because a closed system is maintained and this eliminates the concern for percutaneous tract implantation. However, concern for tumor spillage exists when perforation occurs during retrograde ureteroscopic treatment. Small tumors that are easily accessed are ideal for ureteroscopic treatment since the risk of perforation associated with ureteroscopy is much lower.

There are instances when it is more advantageous to manage upper urinary tract TCC percutaneously rather than ureteroscopically,, especially in the setting of large tumors or tumors located in the lower pole calyx. Percutaneous access to the kidney provides versatility by allowing larger scopes and instruments into the upper urinary tract, which enhances the ability to ablate the tumor. Even with the superior ability to deflect, the lower pole is often difficult to access with a flexible ureteroscope when a laser fiber or bugbee electrode is passed through the working port. Moreover, the irrigation through the flexible ureteroscope becomes limited, and even slight bleeding often obscures visualization when ablating tumor with either laser fiber or bugbee electrodes.

Patients with a history of bladder cancer who have undergone radical cystectomy with urinary diversion are difficult to manage as well. The retrograde approach to inspect the upper urinary tract in urinary diversion is a challenge, especially "Bricker type," end-to-side ureteroenteric anastomosis. These patients require the percutaneous approach to obtain access into the upper urinary tract [19]. The "Wallace type" end-to-end ureteroenteric anastomosis may allow slightly easier access ureteroscopically, but this is still challenging and a percutaneous approach is usually required [20].

The percutaneous approach offers advantages over ureteroscopic treatment for reasons other than the limitations of flexible ureteroscopy, as mentioned briefly above. One of the major benefits of percutaneous treatment is that nephroscopes and resectoscopes are much larger than ureteroscopes, and therefore provide superior visualization from the optical standpoint. Irrigation flows much more freely and maximizes visualization. Larger working channels allow larger instruments to pass, in turn providing much better tissue sampling, and hence improving staging capabilities. Large tumors are ablated much more efficiently and operative time is reduced. A percutaneous nephrostomy tube is left in place at completion of resection. It allows proper drainage and serves to achieve hemostasis. It also allows subsequent re-examination or serves as percutaneous access if instillation of intracavitary agents into the upper urinary tract is considered. Although percutaneous management may pose more risks than ureterscopic management, there are circumstances where treating upper urinary tract TCC percutaneously are much more advantageous [21, 22].

Puncture selection

The principles of obtaining access for percutaneous nephrolithotomy apply for percutaneous treatment of upper urinary tract TCC. As the puncture site moves more medially, the risk of injury to the renal vessels increases and direct puncture into the renal pelvis may occur. The latter should be avoided since the posterior branch of the renal artery is in close proximity and can cause significant bleeding [23]. In addition, the renal pelvis does not provide stability for the access sheath since there is no parenchymal support, and this may result in a large laceration when manipulating the scope during resection.

The location of percutaneous access is dictated by the location of the tumor. Tumors located in the peripheral calyces are best approached by placing the access in direct line with the tumor and not directly on the tumor. Tumors located in the proximal ureter or renal pelvis may be approached either from the middle or upper calyx to access the ureteropelvic junction (UPJ) in a straight path (Figure 28.1) [24]. More than one access may be required when large tumors are located in different calyces.

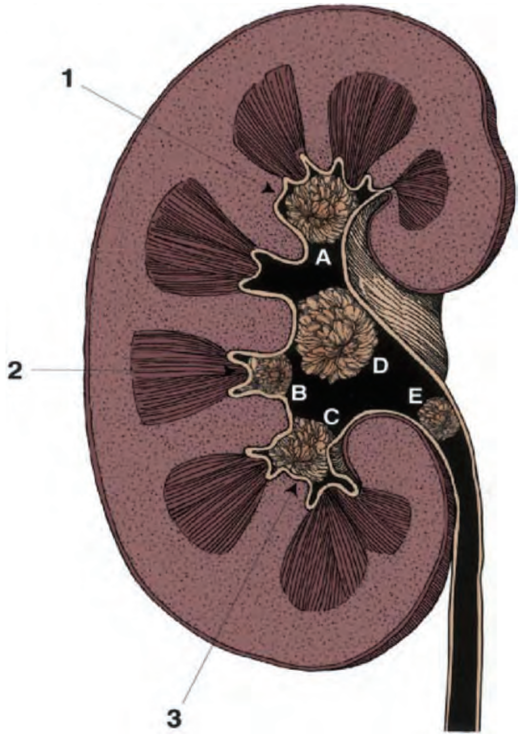

Figure 28.1 Nephrostomy track puncture site. Tumors in peripheral calyces (A–C) are best approached by direct puncture as far distally in the calyx as possible. Tumors in the renal pelvis (D) are upper ureter (E) are best approached by puncture to an upper (1) or middle (2) calyx, which allows the scope to be maneuvered in the renal pelvis and down the ureter. Tumors in the lower calyx are approached by lower calyx puncture (3) (reproduced from Sagalowsky & Jarrett [24], with permission).

Techniques of resection

After gaining percutaneous access, there are different methods to achieve resection or ablation of upper urinary tract TCC (Figure 28.2) [24]. Resection of tumor can be achieved with monopolar or bipolar loop electrodes, or tumors can be ablated with lasers.

A large access sheath allows a standard resectoscope with cutting loop to be introduced into the upper urinary tract. The access sheath maintains a low pressure system with irrigation through the scope. With the standard monopolar cutting loop, the tumor is electrosurgically resected to the base and the specimen is extracted (Figure 28.2A). This technique works well for papillary tumors on a narrow stalk (Figure 28.3). Broad-based tumors may cause excessive bleeding and are best approached with resection of the laser therapy. Hemostasis is easily accomplished at the base of the resection by electrocautery. In addition to resection, electrovaporization can be accomplished with a 200-W pure cutting current of the monopolar device [25]. The increased current causes immediate cell death by direct vaporization and the underlying tissue is desiccated and coagulated [15].

Another type of resection device is the bipolar loop electrode. This device also has been utilized for treating benign prostatic hyperplasia. The irrigation medium used for bipolar electrodes is normal saline, which minimizes the change in serum sodium and other electrolyte abnormalities during resection. When water is used as an irrigation medium, hyponatremia and other electrolyte abnormalities may occur [26, 27]. With the bipolar loop resection, deep tissue sampling is possible, just as with the standard monopolar loop [28]. Hemostasis is achieved in a manner similar to that with the monopolar loop.

Tumor ablation can also be accomplished using lasers (Figure 28.2B–D). The neodymium (Nd):YAG and holmium (Ho):YAG are two well-established laser systems in urology. The induced effects on soft tissue vary between coagulation, vaporization, and incision, depending on the contact versus noncontact mode. Both lasers on contact mode have the capability to vaporize or incise tissue.

The Nd:YAG laser is well-suited and widely used for bladder tumors and upper urinary tract TCC. The noncontact mode of this laser will coagulate the tumor. The Nd:YAG laser fiber is placed in close approximation to tissue, but not in direct contact, and the laser is activated at around 20–30 W to coagulate the tissue [6]. The distal fiber tip should be directed tangentially in a noncontact mode until the tissue coagulates. This laser penetrates tissue to a depth of approximately 5–6 mm, so bulky tumors are ablated much more efficiently. Due to the depth of penetration, the Nd:YAG laser should never be used circumferentially in the ureter, as it may cause ureteral stricture [29]. As the tissue coagulates, the coagulated portion of the tumor is removed with forceps, which exposes deeper portions of the tumor that require further coagulation. The coagulation and ablation is repeated until the base of the tumor is exposed.

In contrast, the Ho:YAG laser must be in direct contact with the tumor to coagulate, vaporize, and incise tissue. It has a penetrating tissue depth of 0.5 mm. The shallow depth of penetration allows the tissue ablation to be focused and circumferential lesions to be treated. However, it will not coagulate large vessels [30, 31]. Thermal energy generated by the Ho:YAG laser is highly absorbable by water so that the heat disperses very rapidly through the irrigation medium. This physical property results in minimal thermal damage to the surrounding tissue [32]. However, one of the drawbacks of Ho:YAG laser is that the tumor adheres to the tip of the fiber during ablation, which often decreases visualization and ablation capacity. This can be minimized by cleaning the fiber tip but the cleaning process adds to

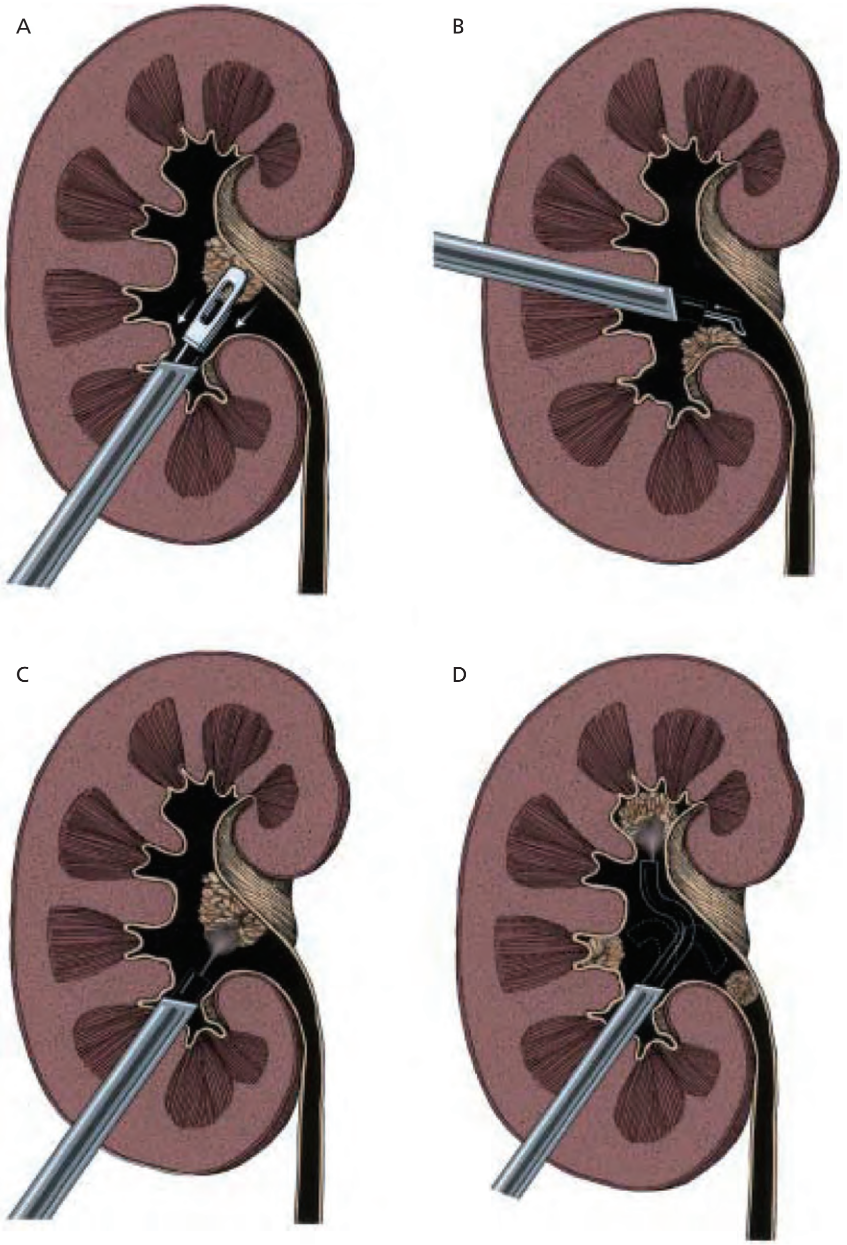

Figure 28.2 Resection of upper urinary tract transitional cell carcinoma. (A) The tumor is identified and debulked by forceps to its base. The base is sampled and sent separately for evaluation. (B) With the use of a standard resectoscope, the tumor is identified and resected to its base. Special care should be taken to avoid resection into major renal vasculature. The tumor is sampled for diagnostic purposes and treated by holmium or neodymium laser sources. This can be done through a standard nephroscope (C) or with a flexible cytoscope (D) (reproduced from Sagalowsky & Jarrett [24], with permission).

operative time. A gentle flow of irrigation is used to clear tumor debris during the ablative treatment.

A combination of the two lasers can be used during one procedure. The Nd:YAG laser can coagulate the majority of the volume of a large tumor, and then the Ho:YAG laser can be employed to ablate the remaining tumor tissue [33]. Particular attention should be given to ensure that the fiber tip is visible in front of the scope at all times.

Complications

Complications from percutaneous treatment of upper urinary tract TCC are much more common than from

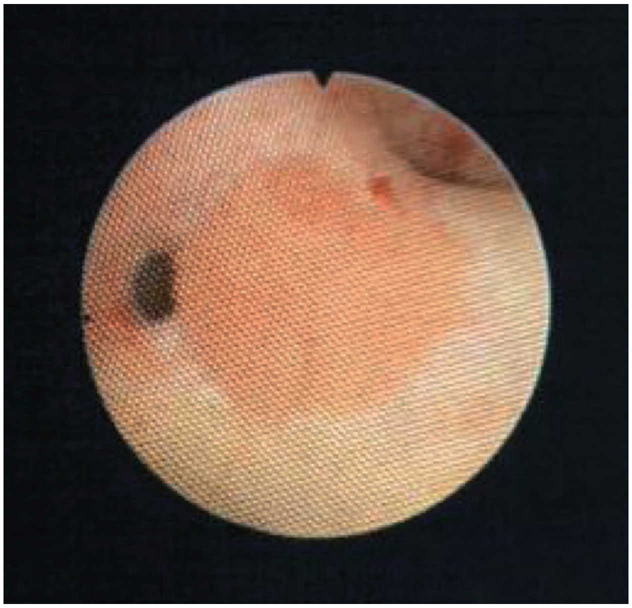

Figure 28.3 Papillary tumor.

the ureteroscopic approach: hemorrhage, urinary tract perforation, UPJ obstruction (UPJO), and pleural, bowel, and spleen injury.

The most common complication due to percutaneous treatment is hemorrhage. Transfusion requirements can range from 20% to 50% [34, 35]. The amount of bleeding is directly related to the grade and stage of the tumor because high-grade and -stage tumors require deeper resection, which may lead to increased postoperative bleeding [36]. Risks for postoperative bleeding also increase with multiple punctures and access, medial puncture, abnormal renal anatomy, and patients on anticoagulants. Blood loss during the procedure is usually managed conservatively with large-bore nephrostomy tube placement to tamponade bleeding from the percutaneous tract, bed rest, and blood transfusion; however, refractory bleeding may require angiographic embolization.

Delayed bleeding may occur from pseudoaneurysm or arteriovenous fistula formation. Pseudoaneurysm results from the weakening of the vessel wall, which is caused by the dilation of the percutaneous tract. This leads to intermittent bleeding into the collecting system, and patients usually present with hematuria with or without clots. Arteriovenous fistula results when injury near the proximal artery and vein occurs, which allows blood to flow from the high to low pressure system. Delayed bleeding is a serious complication that needs immediate attention. If not treated immediately with angiographic embolization, it can lead to a catastrophic event.

Urinary tract perforation can occur during resection or when obtaining access. When the injury is unrecognized during the resection, the perforation can inadvertently get larger, and it can lead to a massive hydroabdomen [37]. One method to minimize perforation is the use of a large access sheath to create a path of low resistance through which irrigant can exit freely. This reduces the pressure within the collecting system while allowing good visualization. Once the perforation is recognized, the procedure should be stopped and maximal drainage of the upper urinary tract should be accomplished with an internal stent and percutaneous nephrostomy tube.

UPJO can occur from overzealous cautery and/or resection, especially when cautery is performed circumferentially. Aggressive maneuvering of the scope can cause mucosal abrasion and edema, obstructing the UPJ, and can also disrupt the UPJ. Surgeons should take particular care when using larger scopes in order to minimize trauma to the UPJ.

Pleural injury can occur, especially when the access is obtained supracostally. Since the pleural space extends inferiorly to the 11th or 12th rib posteriorly, the violation of the pleural cavity is a well-known complication [38]. Pleural injury is recognized at the end of the procedure by intraoperative fluoroscopy, and usually the hydrothorax or pneumothorax can be seen. When this is confirmed, it can be managed with postoperative insertion of a chest tube or thoracentesis [39]. A small chest tube (10F) can be placed intraoperatively under fluoroscopic guidance while a patient is still under general anesthesia. A percutaneous renal access needle is placed perpendicular to one of the intercostal spaces along the posterior axillary line. The Seldinger technique is performed to place a small chest tube into the thoracic cavity [40].

Although uncommon, injury to the adjacent organs such as the bowel or spleen can occur. Colonic perforation can occur in patients with anatomic renal abnormalities, such as horseshoe kidney, renal fusion, and renal ectopia. Rare anatomic abnormalities, such as a retrorenal colon, can also predispose patients to colonic injury. In general, the risk of bowel perforation is increased with more lateral puncture. If the bowel perforation is contained in the extraperitoneum, it is treated conservatively with a ureteral stent and placing a tube into the lumen of the bowel to separate the two systems. If the bowel perforation is intraperitoneal, surgical correction should be considered. Injury to the spleen may occur in patients with splenomegaly. When a spleen laceration is encountered, surgical exploration should be considered due to significant hemorrhage.

Access tract seeding is an important consideration for percutaneous procedures for upper urinary tract TCC. While rare, there have been a few reported cases of the percutaneous tract recurrence of TCC [22, 41–43]. As mentioned earlier, the use of a large access sheath decreases the intrarenal pressure, and it may minimize tumor implantation of the percutaneous tract [6]. Most of the tract recurrences occur with high-grade TCC. However, low-grade disease can also implant and cause recurrence if tumor spills into the wound and when proper surgical technique is not maintained [44, 45]. Interestingly, tract seeding has been reported for renal cell carcinoma as well [42].

Second-look nephroscopy

Percutaneous management should incorporate the goal of complete resection. This can be achieved by second-look nephroscopy to confirm complete resection and reassess residual tumor burden. The percutaneous tract is typically maintained with a 24F nephrostomy tube, and second-look nephroscopy is performed usually within 4–7 days after the initial treatment. The main objective of a second nephroscopy should be to re-resect any residual tumor and/or fulgurate the base of tumor. A third nephroscopy can be considered 2 weeks after Bacillus Calmette-Guérin (BCG) instillation when the index of suspicion is high, and random biopsy or tumor resection may be performed again at that time [34]. However, at any time, invasive or high-grade disease should prompt nephroureterctomy with ipsilateral bladder cuff excision if the patient is able to tolerate radical extirpirative surgery or is not expected to require hemodialysis.

Intracavitary BCG, administered via percutaneous nephrostomy tube, can be considered after the second-look nephroscopy. The objective is to reduce recurrence and progression of disease. BCG is administered once weekly for 6 weeks (see below and Chapter 26).

An algorithm for percutaneous treatment of upper urinary tract TCC is depicted in Figure 28.4.

Results

The first series of percutaneous management of upper urinary tract TCC was described in patients with solitary kidney by Smith *et al*. in 1987 [45]. Since then, numerous studies have described the percutaneous management of upper urinary tract TCC (Table 28.2) [22, 34, 46–48]. As mentioned earlier, the recurrence and progression of upper urinary tract TCC depend on grade and stage of the original tumor, the two most important prognostic factors. Recurrence for low-grade tumors occur at much lower rates (18–28%) than for high-grade tumors (50%) [34, 47].

Grade 1 tumors are most often superficial tumors without submucosal invasion. Risk of metastatic disease without submucosal invasion appears to be minimal, and the recurrence rates demonstrated by Jarrett *et al*. and Clark *et al*. for low-grade tumors are 28% and 18%, respectively [34, 47]. The percutaneous resection is well tolerated and it can be repeated if upper urinary tract TCC recurs. Grade 2 tumors behave more aggressively than grade 1 tumors, with higher invasive potential that often results in understaging due to inadequate resection. There is a higher complication rate compared to that for low-grade tumors, resulting from the more aggressive resection, since grade 2 tumors tend to invade deeper than the mucosa. Grade 3 tumors behave very aggressively, with most found to invade into or beyond the submucosa. The recurrence rate for grade

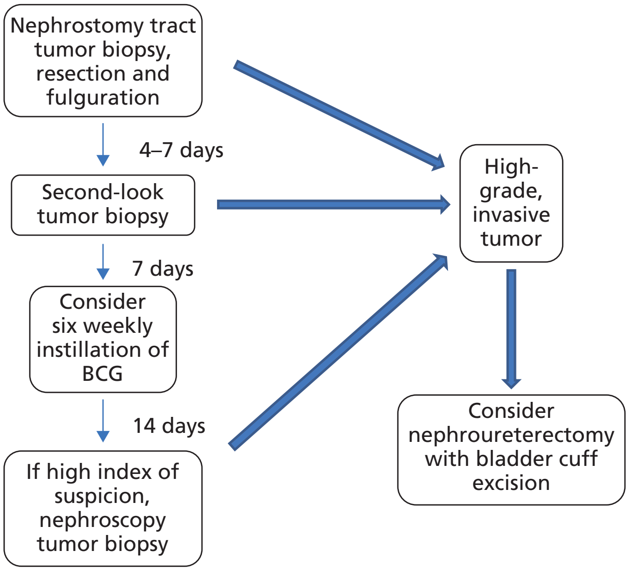
Nephrostomy tract tumor biopsy, resection and fulguration
4–7 days
Second-look tumor biopsy
7 days
Consider six weekly instillation of BCG
14 days
If high index of suspicion, nephroscopy tumor biopsy
High-grade, invasive tumor
Consider nephroureterectomy with bladder cuff excision

Figure 28.4 Percutaneous management of the upper tract transitional cell carcinoma.

Table 28.2 Results of percutaneous approach for upper urinary tract transitional cell carcinoma.

Series	Number of patients	Recurrences (%)	Nephroureterectomies (%)	Duration of study (months)
Jarrett *et al*. 1995 [34]	36	10 (28)	15 (42)	9–111
Patel *et al*. 1996 [46]	28	6 (23)	6 (23)	1–100
Clark *et al*. 1999 [47]	18	6 (33)	2 (11)	2–76
Palou *et al*. 2004 [48]	34	14 (41)	11 (25)	Mean 51
Roupret *et al*. 2007 [22]	24	8 (32)	(20)	Mean 62

3 is as high as 50% [34, 47]. In their series, Jabbour *et al*. and Jarrett *et al*. demonstrated that all deaths during follow-up occurred in patients with grade 3 disease [18, 34]. Death was reported in these patients whether they had local recurrence or not, which suggests the aggressive nature of high-grade tumors with higher metastatic potential.

Patients with confirmed grade 3 disease have been considered for radical nephroureterectomy with bladder cuff excision [22, 34, 46–48], but this has not shown significant survival benefit when compared to patients who underwent percutaneous resection alone [49]. These data indicate that higher histologic grade tumor presents with more advanced disease and radical surgery may have no bearing on survival benefit. Given that survival benefit is questionable, percutaneous management may provide improved quality of life if the need for dialysis is delayed.

Percutaneous management is an option for certain cohorts of patients, particularly the elderly. Kang *et al*. reported 2- and 5-year survival rates of dialysis patients with primary upper urinary tract TCC of 74% and 43%, respectively [50], and Jager *et al*. reported 2-year survival of 51% in dialysis patients [51]. Not unexpectedly, mortality is higher among elderly dialysis patients [52]. According to the American Society of Nephrology (ASN), elderly patients in preterminal stages should receive information regarding life-expectancy before dialysis is considered [53]. Interestingly, a large cohort of elderly patients on dialysis revealed that they perceive themselves as physically inferior to the general population of the same age [54]. Heart disease, hypotension, intestinal bleeding, and amyloidosis are significant elements of dialysis in the elderly population that can dramatically affect quality of life.

Intracavitary therapy

The mainstay of intravesical treatment for superficial bladder cancer has been the use of BCG [55, 56], but other intravesical chemotherapeutic agents have been used (see below and also Chapter 26). The response rate for superficial bladder cancer has been variable depending on the intravesical chemotherapeutic agent used. To replicate the superficial bladder tumor response data from intravesical BCG treatment, the use of BCG for upper urinary tract TCC was first described by Herr in 1985 [57].

The safety of administration of BCG into the upper urinary tract is well-established [58]. Notwithstanding this fact, some have expressed concern for systemic BCG infection. Usually, patients present with high fevers, rigors, and malaise, which mimic a general infectious process. Fortunately, when patients present with fevers, they are usually caused by urinary tract infection and not systemic BCG infection [59]. Fevers should alert the urologist to the possibility of BCG sepsis. BCG sepsis has devastating sequelae and serious steps should be taken to prevent systemic BCG infection. In order to decrease the likelihood of systemic BCG infection, the percutaneous tract is allowed to mature for 1–2 weeks after resection if the patient is to be treated with BCG [49, 60]. Typically, patients have a urine culture from the percutaneous nephrostomy tube, and receive antibiotics prior to BCG instillation.

Safety measures can be practiced to minimize complications from BCG instillation into the upper urinary tract. Typically, normal saline is infused via the percutaneous nephrostomy tube, starting at a very slow rate, and gradually increasing to a rate of approximately 50 mL/h. Normal saline is continued for approximately an hour with intrapelvic pressure monitored to maintain it at less than 25 cmH_2O (Figure 28.5) [24]. At that point, the BCG is instilled under gravity via the percutaneous nephrostomy tube. The instillation should be stopped if the intrapelvic pressure increases above 25 cmH_2O or the patient complains of fever or pain. It is important to monitor the intrapelvic pressure because high pressure can lead to pyelovenous backflow of BCG, which can increase the risk of BCG sepsis. BCG is instilled once a week for 6 weeks. After the completion of six cycles of BCG, another nephroscopy is considered when the index of suspicion is high, and usually performed 2 weeks after the last cycle of BCG instillation. When tumor or abnormal mucosa is encountered, it can be biopsied and treated.

Another method of instilling BCG is using a retrograde approach. A straight ureteral catheter is placed into the renal pelvis endoscopically and BCG is instilled into the renal pelvis. This method requires that patients be admitted to hospital and observed after instillation. The instrumentation can cause significant ureteral edema, which can lead to ureteral obstruction and Gram-negative sepsis if care is not taken. Another disadvantage of this method is that patients will need endoscopic placement of a straight catheter with every instillation. To circumvent this issue, a single-J stent can be placed percutaneously via cystotomy, obviating the need for the endoscopic procedure [61].

Alternatively, a refluxing double-J stent may be placed endoscopically and intravesical BCG instilled, allowing intravesical BCG to reflux up into the renal pelvis. The amount of intravesical fluid needed to induce reflux ranges from 80 to 250 mL (median of 120 mL) [62]. Cystography is performed to confirm reflux since a double-J stent does not guarantee reflux [63].

Ureteral meatotomy can be performed to cause vesicoureteral reflux. After the double-J stent is removed, reflux is confirmed with cystography and the volume necessary to cause reflux is recorded. An

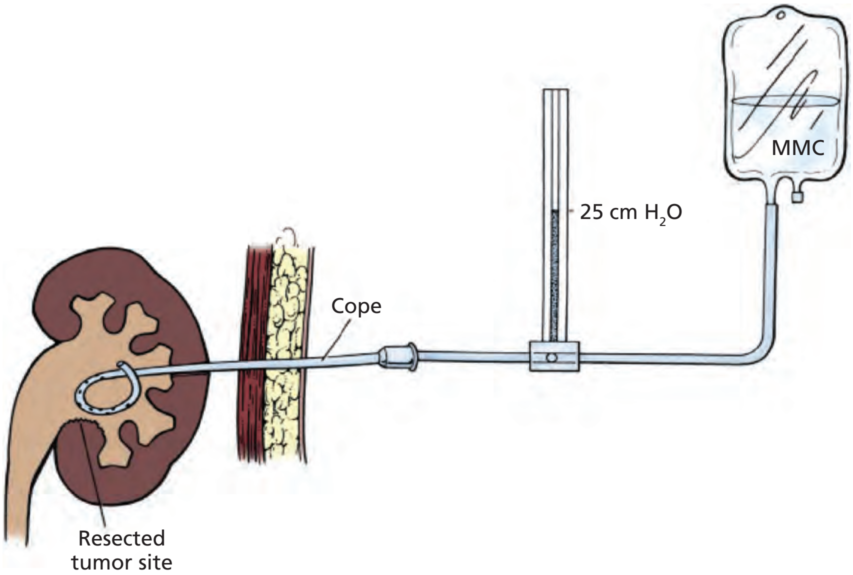

Figure 28.5 Set up for administration of topical immunotherapy or chemotherapy to the upper urinary tract through a previously placed nephrostomy tube. Therapy is instilled under gravity with a mechanism that prevents excessive intrarenal pressures. MMC, mitomycin C (reproduced from Sagalowsky & Jarrett [24], with permission).

appropriate volume of BCG can be administered intravesically [64].

Reports of the efficacy of BCG treatment for the upper urinary tract have been conflicting. However, most data show that survival benefit from intracavitary BCG therapy is inadequate [34, 47]. Hayashida *et al.* demonstrated a 50% recurrence rate, and showed 100% mortality for patients in whom TCC recurred after BCG treatment [65]. In contrast, Okubo *et al.* found some long-term benefit with tumor-free survival at a median follow-up of 46 months in their cohort [66]. Data should be interpreted very cautiously since instillation of BCG does not seem to prevent recurrence or progression of the higher-grade upper tract TCC. However, there may be some benefit for low-grade tumors and carcinoma *in situ* [67]. One major issue for advanced and/or high-grade tumors is that the BCG instillation regimen will allow these tumors to progress while the six cycles are completed. Due to the inadequate response to BCG, some advocate CT scans to monitor lymph nodes or metastatic status during the six cycles of BCG.

Other intracavitary agents that have been studied are mitomycin C and thiotepa. Keeley *et al.* instilled mitomycin C after ureteroscopic treatment in 19 patients. Eleven patients had a good response and were to tumor free during follow-up [44]. Martinez-Pineiro *et al.* observed a lower recurrence rate for patients who were treated with BCG and mitomycin C than for patients who were treated with thiotepa [11].

Unlike the intravesical BCG therapy for superficial bladder TCC, statistically significant survival benefit has not been demonstrated for upper urinary tract TCC. A randomized trial to study the efficacy of intracavitary therapy of upper urinary tract TCC is necessary.

Follow-up

Careful follow-up and evaluation of upper urinary tract TCC is crucial, and it should be performed so that recurrences are recognized and treated quickly. Any signs and symptoms should prompt further investigation. There are no set guidelines for the evaluation of percutaneously managed upper urinary tract TCC, but short-interval evaluation is strongly encouraged during the first few years after initial percutaneous resection. Patients are typically evaluated once every 3 months for a year, every 6 months for 4 years, and then annually. Iwaszko *et al.* recommend ureteroscopy once every 3 months for the first 2 years, then every 6 months for the next 2 years, and then annually [36]. The surveillance protocol should include history and physical examination, urine cytology, cystoscopy, and CT urogram or retrograde pyelogram [34]. Ureteroscopy and upper urinary tract cytology are performed on the basis of suspicion for recurrence. Upper tract imaging should include the contralateral kidney. With the advent of superior optics and smaller ureteroscopes, ureteroscopy is much more sensitive than intravenous urogram, and the tumor can be treated at the time of diagnostic ureteroscopy.

High-grade TCC has a greater tendency to recur and potential for stage migration, and it requires more vigilant follow-up with a higher index of suspicion for recurrence during evaluation.

Conclusions

The percutaneous treatment of upper urinary tract TCC is feasible and sometimes necessary for a certain group of patients. When the nephron-sparing endoscopic approach is chosen to treat upper urinary tract TCC, a proper follow-up plan is absolutely necessary. Higher grade tumors should prompt a more rigid follow-up plan, as they behave more aggressively than lower grade tumors.

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PART 7 Exit Strategy and Complications

CHAPTER 29

Exit Strategy After Percutaneous Renal Surgery: Drainage and Hemostasis

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History and introduction

Fernstone and Johanson first described percutaneous nephrolithotomy (PCNL) in 1976 [1] for the management of renal pelvic calculi. Since then, this technique has become an established treatment modality and the primary option for management of patients with large stone burden in the renal pelvis [2], ureteropelvic junction obstruction (UPJO) [3], and upper tract transitional cell carcinoma (TCC). There has been constant innovation and experimentation with new techniques in all aspects of percutaneous renal surgery, including access into the kidney, tools for surgery, including optics and instrumentation, and exit strategy. In this chapter we will discuss the last of these.

It was routine practice to leave a wide-bore nephrostomy tube after percutaneous renal surgery (which includes PCNL, antegrade endopyelotomy, and urothelial cancer resection) to address the twin issues of hemostasis and drainage. But these tubes were large, cumbersome, and a significant source of pain for patients, resulting in postoperative morbidity and hence the incentive for improvement. Urologists prompted improvements in the design of the nephrostomy tube with caliber reduction to improve outcomes [4]. Eventually they started questioning the very need for a nephrostomy tube itself. In 1997, Bellman *et al*. reported tubeless PCNL as an alternative to nephrostomy tubes as an exit strategy after PCNL [5]. Since then this technique has been reported to have multiple advantages, including decreased postoperative pain, shorter hospital stay, and decreased analgesic need [6].

The exit strategy after PCNL has been a topic of controversy in recent years. As mentioned, wide-bore nephrostomy tubes were placed routinely after percutaneous renal surgery both to drain the kidney, and tamponade the access tract and establish hemostasis (although there is no evidence to support this assumption). The nephrostomy tube also allows clearance of blood clot, provides an access for a nephrostogram to be performed in the postoperative period, and permits access into the collecting system for a re-entry procedure in a staged nephrolithotomy. Recently the routes to establish hemostasis and provide drainage have diverged into separate strategies.

Drainage of the kidney was addressed with placement of stents or even “totally tubeless” PCNL. Paralleling these changes in drainage aspect, new techniques were reported to establish hemostasis of the tract. These included using gelatin matrix hemostatic sealant [7], cauterization of tract and tissue sealants [8], and Surgicel to maintain hemostasis and aid closure of tract. We reported our experience with cryoablation of the nephrostomy tract with a single freeze–thaw cycle to establish hemostasis [9]. Together, these new techniques for drainage of the kidney and hemostasis may open new avenues of minimally invasive management, even for patients undergoing complicated PCNL.

We will discuss drainage and hemostasis in separate sections with detailed analysis of available evidence and possible recommendations.

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Table 29.1 Types of nephrostomy tubes (NTs), properties and uses (reproduced from Srinivasan *et al.* [10]).

Text not available in the electronic edition

Drainage of the renal pelvis

It should be emphasized that the terminology of the newer drainage techniques needs to be standardized to achieve uniformity in reporting and avoid misconceptions. In this chapter, we define PCNL with a nephrostomy tube as "tubed PCNL," PCNL with ureteral stents only as "stented PCNL," and totally tubeless PCNL as "tubeless PCNL."

There are three main techniques for drainage of the collecting system after percutaneous renal surgery: nephrostomy tubes, ureteral stents, and totally tubeless surgery. It is important to mention that the options of ureteral stents and tubeless surgery have only been studied in low-risk PCNL and to some extent can be applied to antegrade endopyelotomy with necessary modifications. We do not have any evidence to use the modified drainage options in patients undergoing resection of TCC in the renal pelvis or ablation of calyceal diverticulum. Hence, the most important factors that should govern the technique for drainage of the kidney are indications for the procedure, operative course, procedural complexity, stone burden, and the clinical status of the patient. One universal solution is not applicable for all patients undergoing percutaneous renal surgery.

Nephrostomy tubes

"An ideal nephrostomy tube should be strong and biocompatible, well tolerated by the patient, resist obstruction or dislodging, and be simple to insert or replace" [4]. As in many cases, an ideal solution does not exist. Each of these tubes has its own unique characteristics (Table 29.1) and this make their use optimal in different clinical situations. Operative course and complexity of procedure and other added procedures, like endopyelotomy and opening of a calyceal diverticulum, mainly dictate the choice of nephrostomy tube. We recently reviewed various drainage options after PCNL and would recommend this report to readers for further detailed analysis [10].

Utility of "mini-perc" percutaneous nephrolithotomy

A number of clinicians considered that the size of the nephrostomy tract and consequently drainage tube are important determinants of postoperative pain, bleeding complications, and hospital stay. The "mini-perc" technique uses a tract dilation up to 13F in adults [11] and 11F in children [12] instead of the 30F tracts and placement of 6–8F nephrostomy tubes and double-J ureteral stents at the end of the procedure. The mini-perc technique has shown excellent stone clearance rates, but the benefit of less postoperative pain has not been demonstrated. The reports were small retrospective series with no control population, smaller stone burden, and placement of both nephrostomy tubes and double-J ureteral stents. The added disadvantages of poor visualization of large stones with smaller caliber instruments [13] make it a less optimal technique.

In conclusion, "mini-perc" nephrolithotomy does not have any proven advantage to decrease pain or other postoperative complications when compared to traditional PCNL. It might have a role in children given the advantage of smaller incision and nephrostomy tracts, although there is no level 1 evidence to support this.

Small-bore nephrostomy tube

Maheshwari *et al*. prospectively compared placement of a 9F small-bore nephrostomy tube to a 28F nephrostomy tubes after routine 30F nephrostomy tracts [14]. Their results showed that patients with the 9F tubes had significantly lower analgesic requirements and duration of urine leak compared to patients with larger sized tubes. The 9F tube did not increase the risk of postoperative bleeding in these patients. In a randomized comparative study, Pietrow *et al*. demonstrated only a statistically insignificant trend towards decreased pain perception and analgesic requirements in patients with a 10F pigtail nephrostomy tube compared to patients who had a 22F Council-tip catheter as a nephrostomy tube [15]. They too did not find any adverse effect of using a smaller nephrostomy tube. Absence of power calculation and nearly 50% of their patients having supracoastal access might have been confounding factors.

Sixty patients undergoing PCNL in our institution were randomized into three groups based on technique of postoperative drainage: 24F re-entry nephrostomy tube, 8F pigtail catheter, and 16F Council-tip catheter with double-J stent. There was no difference in any postoperative complication, including bleeding, pain, or analgesic requirements. The group with the 8F pigtail catheter had significantly less urine leak when compared to the other two groups.

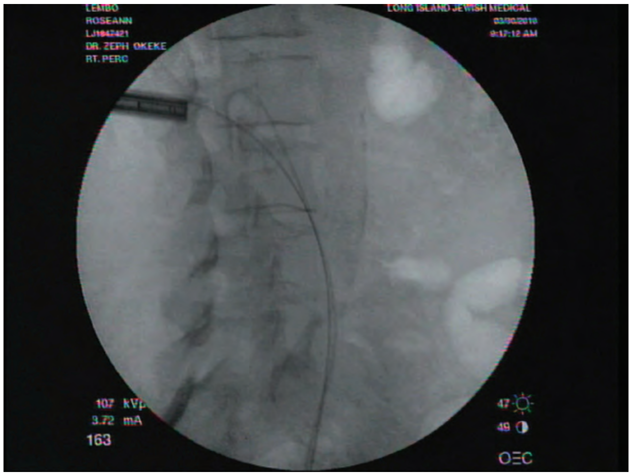

Figure 29.1 Placement of antegrade ureteral stent under fluoroscopic guidance.

Smaller nephrostomy tubes may be advantageous in terms of pain control and analgesic requirements, but this has not been universally demonstrated. The size of the drainage tubes does not have any relation to the risk of postoperative bleeding in patients undergoing PCNL.

Stented percutaneous nephrolithotomy

Stented PCNL has primarily involved placement of a 6F double-J ureteral stent either antegrade or retrograde at the end of the primary procedure. This procedure was initially called tubeless PCNL, which is actually a misnomer. As reported by Monga *et al*., we prefer the term stented PCNL to tubeless PCNL, since these patients do have stents and hence are prone to symptoms from the stent tube as opposed to the nephrostomy tube [16]. Antegrade placement of a ureteral stent through the access sheath under fluoroscopic guidance is illustrated in Figure 29.1.

Stented PCNL was first reported by Bellman *et al*. in 1997 [17], challenging the routine use of a nephrostomy tube after PCNL. Although their study population was small, they reported dramatically reduced hospital stay, postoperative pain, and analgesic requirements; as hospital cost was halved, the authors had a very persuasive case for performing tubeless PCNL. A follow-up study by the same authors, with results for 112 patients – 86 undergoing isolated PCNL and 26 PNCL and endopyelotomy, showed a stone clearance rate of 93% and a UPJO resolution rate of 88% [18]. Although this study demonstrated wider application for tubeless PCNL, their study population was highly selected. Their exclusion criteria were procedure lasting longer than 2 h, three or more percutaneous accesses, perforation of the collecting system, significant bleeding (not defined in the original paper), and the need for second-look nephroscopy.

Since these publications, there has been widespread interest in and enthusiasm for stented PCNL. Many authors have reported their experience with stented PCNL [19, 20] and there have been comparative studies between standard and stented PCNL [13, 21–23]. Some of these comparative studies [21] and other studies [24, 25] have also looked at stented PCNL versus small-bore nephrostomy tube placement after standard PCNL. More recent literature is available on the feasibility of stented PCNL in children [26], obese patients [27], supracostal access [28], patients with renal anomalies [29], and in an outpatient setting [30]. All these studies with stented PCNL had very strict inclusion criteria and the results are not applicable to all patients undergoing PCNL. These strict criteria include short procedures, uncomplicated procedures, minimum blood loss, no pelvic wall perforation, minimal tracts, complete stone clearance, and absence of need for second look. Although the safety and feasibility have been demonstrated by these studies in a select group of patients with strict inclusion criteria, there are no comparative studies demonstrating superiority of stented PCNL to traditional PCNL.

Feng *et al*. from Bellman's group compared traditional PCNL with wide-bore nephrostomy tubes versus "miniperc" versus stented PCNL, and reported best outcomes in patients undergoing stented PCNL, but this study is burdened by small sample size and significant patient selection [13]. Agrawal *et al*. reported a randomized comparison of standard PCNL with tubeless PCNL in 222 patients with similar restrictive criteria and a less than optimal randomization process; superior outcomes in terms of postoperative pain and hospital stay were reported for patients undergoing tubeless PCNL [22].

Problems with stented percutaneous nephrolithotomy

Desai *et al*. reported a three-arm study comparing standard PCNL drained with a 20F nephrostomy tube, standard PCNL drained with a 9F tube, and stented PCNL; best outcomes were for patients undergoing stented PCNL [21]. Although the authors did not observe any stent-related pain in their patients, they concluded that "small-bore nephrostomy drainage may be a reasonable option in patients who might have stent dysuria." Shah *et al*. attempted direct comparison of stented PCNL with small-bore nephrostomy drainage in a randomized fashion and reported less postoperative pain in the stented group [25]. They used a formal questionnaire in the immediate postoperative period and after discharge to evaluate stent-related discomfort. Nearly 40% of their stented PCNL patients had "bothersome stent-related symptoms" and around 60% of them had analgesia and/or antispasmodics to treat these symptoms. Choi *et al*. compared stented PCNL with tethered stents placed retrograde, aiding removal without a cystoscope, with 8F nephrostomy drainage after PCNL in a randomized study [24]. They concluded that both groups had similar levels of postoperative pain and length of hospital stay, but stent dislodgement was seen in 25% of the stented patients, almost exclusively in women. Although this high rate of stent dislodgement in this study may be attributed to the tether and the way it is secured, dislodgement is a significant problem in all stented PCNL and may necessitate secondary interventions.

Most of the literature comparing nephrostomy tubes and stents were performed in the setting of ureteral obstruction without percutaneous surgery [31]. Hence, they may not be equipped to compare nephrostomy tubes and ureteral stents in the setting of post-PCNL quality of life issues like pain, bother score, and dislodgement rate. At present, we could not find any study that addresses this specific question.

Tubeless percutaneous nephrolithotomy

Totally tubeless PCNL is in its very early stage of reporting in the literature. Goh *et al*. reported the first totally tubeless PCNL in 1999 by managing patients with ureteral catheters that were removed on postoperative day 1 [32]. The first true report of totally tubeless PCNL was by Karami *et al*. in 2004 [33]. Thirty patients who had a ureteral catheter inserted for PCNL and then removed at the end of the procedure (based on operative outcomes) were compared with 30 patients who had ureteral stents and nephrostomy tubes inserted after PCNL. They reported a significantly better outcome for patients without ureteral stents or nephrostomy tubes. Although this study has many flaws, like retrospective comparison, selection bias, and nonstandardized control group, it demonstrated the safety and feasibility of totally tubeless PCNL. More recent studies lend support to the totally tubeless PCNL concept [34]. The first randomized study was reported by Istanbulluoglu *et al*. in a selected population of patients undergoing PCNL [no serious bleeding or perforation in the collecting system during the operation, stone free or clinically insignificant residual fragments (<4 mm), and no more than one access], and compared totally tubeless PCNL with 14F Malecot nephrostomy tubes [35]. The same benefits of stented PCNL with regards to decreased postoperative pain and analgesic requirements, and reduced hospital stay were demonstrated in the totally tubeless PCNL group.

Totally tubeless PCNL may be applicable to a select group of patients who need PCNL, but further studies

Image not available in the electronic edition

Figure 29.2 Classification of percutaneous nephrolithotomy patients and recommendations on exit strategy for renal drainage (reproduced from Srinivasan *et al.* [10]).

are needed to documents the benefit and safety of this procedure before any recommendations can be made.

Recommendations on renal drainage after percutaneous renal surgery (Figure 29.2)

- We recommend using a wide-bore nephrostomy tube for drainage after percutaneous resection of upper tract TCC.
- We recommend using a Council-tip catheter after lysis of infundibular stricture in patients with calyceal obstruction or after ablation of calyceal diverticulum.
- Patients undergoing PCNL, endopyelotomy, or both may have tubed or stented PCNL based on procedural complexity.
- There is level 1 evidence that "stented PCNL" decreases postoperative pain, analgesic requirements, urine leakage, and duration of hospital stay after percutaneous PCNL in a select group of "uncomplicated routine" patients, as defined by our previous study [4].
- The results of stented PCNL cannot be applied to patients who are at higher anesthesia risk (extremes of age have frequently been an exclusion factor, although stented PCNL in now being reported in children), or have more than two dilation tracts, congenital anomalies of the kidney (only case series of stented PCNL in horseshoe kidneys are available), residual stone fragments after procedure, renal pelvis perforation, excessive bleeding (arbitrary – not defined by any studies), other organ injury, preoperative sepsis. and presence of any other intraoperative complications. Hence, these should be considered exclusion criteria based on available evidence.
- We recommend tubed PCNL in all the above patients. The choice of a wide- or small-bore nephrostomy tube is left to the surgeon, although there is evidence that a small-bore nephrostomy tube may decrease postoperative pain and risk of persistent urinary leak. This benefit is without any increased risk of postoperative bleeding
- Currently, there is not enough evidence to recommend tubeless PCNL.

Hemostatic techniques after stented/tubeless percutaneous nephrolithotomy

In patients who are eligible for stented or tubeless PCNL, adjunctive techniques can be utilized to establish hemostasis and aid parenchymal closure. Various options have been explored and these will be discussed below.

Sealants

Sealants are broadly of two kinds – fibrin- and gelatin-based products. The fibrin-based products are liquid agents that contain all essential components required for clot production, i.e. thrombin and fibrinogen. On contact with a tissue surface, the mixture of thrombin and fibrinogen forms a fibrin clot that aids in hemostasis and tissue seal. It is important to note that the fibrin sealants can seal independently of the patient's clotting factors. Gelatin-based products contain thrombin and gelatin. On contact with tissue surface, these products need the patient's own fibrinogen to start a clotting cascade. It has been reported that the gelatin particles aid in this process by providing a matrix for the formation of the clot. They reportedly swell in size by 19–400% and thus have a tamponading effect as well. A detailed review of the various types of sealants available on the market and their unique properties has been reported by Choe *et al*. [36].

The use of sealants after uncomplicated PCNL was first reported by Mikhail *et al*. in a randomized study comparing the use of fibrin glue to establish hemostasis and prevent postoperative complications to a control group [37]. They found no difference between the two groups with regards to postoperative hematocrit change and postoperative pain. The fibrin glue group did not have any increased incidence of postoperative complications. The study showed that use of fibrin glue is feasible in patients, but limited evidence for safety since long-term follow-up was not provided. A similar feasibility study was performed by Noller *et al*. in a small number of patients [38]. Shah *et al*. followed this evidence with a larger randomized study, with 31 patients undergoing uncomplicated stented PCNL in the study arm and 32 patients in the control arm [39]. The study group of patients had Tisseel (fibrin glue) inserted in the nephrostomy tract under fluoroscopic guidance. These patients had less postoperative pain and analgesic requirements compared to the control group, although there was no difference in the postoperative change in hematocrit or blood transfusion requirements. There was no difference in length of hospital stay or in postoperative complications, but again the data are limited due to short follow-up. Surgicel has also been reported in a small sample population to have no effect on postoperative outcomes [40].

Concerns regarding injection of glues into urothelial tracts have surfaced. Clayman *et al*. reported an *in vitro* study on the effect of hemostatic agents when they come in contact with urine [41]. Comparing fibrin sealant, gelatin sealant, Surgicel, and polyethylene glycol, the authors found that the fibrin sealants, Surgicel, and polyethylene glycol formed a gelatinous clot that was still present at the end of 5 days. Gelatin sealant, on the other hand, was suspended in urine as fine particles and did not form a clot that has potential for obstruction or other complications (Figure 29.3). It should be emphasized that there are no long-term studies on the safety of any of these agents when instilled into the urinary tract.

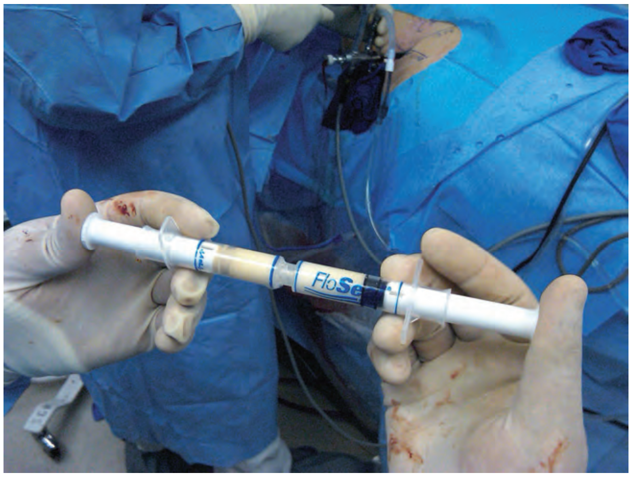

Figure 29.3 Gelatin sealant mixed in preparation for injection into the nephrostomy tract.

The above findings prompted the same group to investigate the use of gelatin sealant in sealing the nephrostomy tract with precautions to prevent free influx of this agent into the urinary tract. They reported on a technique of retrograde occlusion of the nephrostomy tract at the calyceal edge with balloon catheters, and under fluoroscopic guidance, injecting gelatin glue (FloSeal) into the nephrostomy tract [42].

The use of hemostatic sealant in percutaneous renal surgery is in its infancy. The optimal technique of application, agent of choice, and early and delayed complications need to be well charted before this can be recommended as effective management.

Thermoablative techniques

Electrocauterization has been extensively used in endoscopic urologic procedures and an adaptation of this technique to establish hemostasis was described by Jou *et al*. [43]. They reported using an elongated tip on a hand-held cautery device through the nephroscope and cauterizing individual bleeding points. In their series, 249 patients underwent uncomplicated stented PCNL and electrocautery was used to establish hemostasis in this population. Compared with patients who did not have electrocautery, those who did showed decreased need for blood transfusion after electrocautery of the

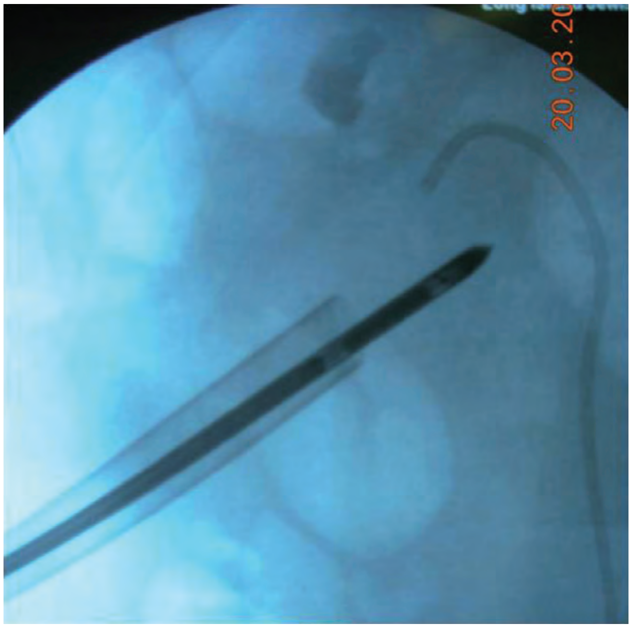

Figure 29.4 Cryoablation needle positioned in the nephrostomy tract under fluoroscopic guidance.

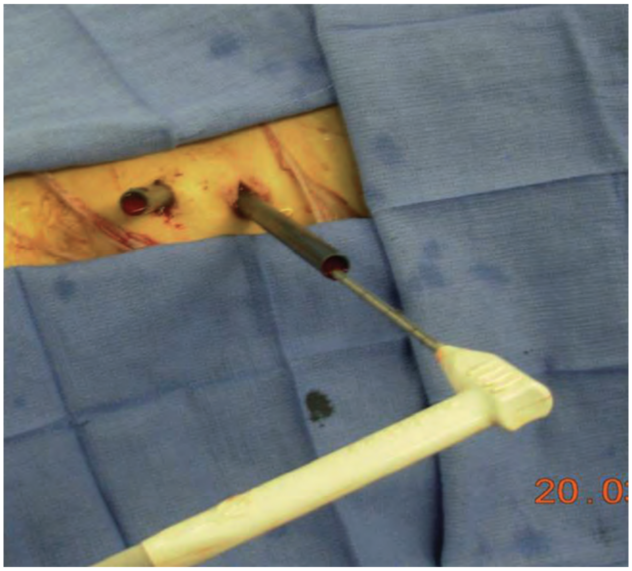

Figure 29.5 Cryoablation needle in position with the sheath pulled back out of the kidney to aid its contact with the parenchyma.

nephrostomy tract. Alternatively, a 26F resectoscope has also been used to electrocauterize the nephrostomy tract [42].

We have reported on the use of a cryofreeze technique to establish hemostasis [9] (Figures 29.4 and 29.5). We retrospectively compared patients after stented PCNL (no selection criteria), including those with multiple tracts, who underwent cryoablation of the nephrostomy tract after complete removal of all stone fragments, with patients who did not undergo ablation. A cryoprobe was positioned under fluoroscopic guidance and one freeze–thaw cycle was utilized to ablate the tract. Our results demonstrate that the cryoablation group had lesser bleeding complications, smaller incidence of urinary leaks, and shorter hospital stay. Although our study is limited by its retrospective nature, it is the first study to explore this technique in all PCNL patients, unlike other studies that have looked at uncomplicated PCNLs only.

Recommendations on hemostatic techniques after percutaneous nephrolithomy

- *In vitro* studies show a better safety profile for gelatin sealants.
- There is no evidence to attribute benefit in using hemostatic and tissue sealants after PCNL.
- No long-term data are available to evaluate the safety of these agents in the collecting system.
- Solitary studies support the use of thermoablative techniques (electrocautery or cryoablation of nephrostomy tracts) for hemostasis after PCNL. There is a paucity of data to make recommendations.

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CHAPTER 30

Hemorrhagic Complications Associated with Renal Surgery

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Introduction

Over the past 30 years, urologists and interventional radiologists have contributed to the evolution of complex open surgical procedures into minimally invasive techniques. For example, the anatrophic nephrolithotomy for the treatment of kidney stones (the Boyce procedure), which was once the gold standard for the treatment of staghorn calculi, has now been replaced by percutaneous nephrolithotomy (PCNL), which offers shorter operative time, lower transfusion rate, lower narcotic requirement, shorter hospital stay, faster convalescence, and lower cost [1]. Minimally invasive procedures have been expanded to include therapies for renal masses. These include laparoscopic partial nephrectomy (LPN), percutaneous tumor ablation using cryotherapy, and radiofrequency ablation. Furthermore, percutaneous biopsy of renal tissue, or needle aspiration, has become a popular tool in the diagnosis of renal masses, as per the recent American Urological Association (AUA) guidelines for small renal masses [2].

Preoperative patient preparation

Initial evaluation of the patient should include a detailed history and physical exam to elicit any signs or symptoms of bleeding dyscrasias. Further work-up as needed by hematology should be performed as an uncorrected coagulopathy is the only absolute contraindication for percutaneous renal surgery. All medications, including over-the-counter herbal supplements that could affect coagulation should be reviewed. Preoperative labs should include a prothrombin time/partial thromboplastin time (PT/PTT), international normalized ratio (INR), complete blood count, and serum electrolytes; and cross-matched blood should be available, depending on the type of case. A preoperative urine culture should be negative.

Another subset of patients who are at increased risk of hemorrhage are those with cardiac stents who are unable to discontinue their antiplatelet medication prior to surgery. It is important to have a discussion with the interventional cardiologist who placed these stents to weigh the risks and benefits of discontinuing antiplatelet agents, such as acetylsalicylic acid (Aspirin) and clopidogrel (Plavix), compared to postponing the planned procedure. These patients should be advised of increased risks of coronary events and postoperative hemorrhagic complications once antiplatelet agents are reinitiated or continued through surgery [3].

The recommendations are as follows: antiplatelet agents, such as acetylsalicylic acid and clopidogrel, should be stopped 10 days prior, warfarin 5 days prior, intravenous heparin 6 h prior, and low molecular weight heparin 24 h prior to surgery [4]. The incidence of thromboembolic events in patients who are off anticoagulation for atrial fibrillation (ischemic stroke) and recurrent deep vein thrombosis/pulmonary embolism (DVT/PE) are 4.5%/year and 7.2%/year, respectively [5]. When the daily incidence is calculated, the risks are small but tangible. Therefore, these patients should also be advised of the increased risks of thromboembolic events

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and postoperative hemorrhagic complications that may occur once anticoagulation therapy has been reinitiated.

Risk of hemorrhage with renal procedures

Percutaneous renal biopsy

In the USA, the incidence of renal cell carcinoma (RCC) has been increasing steadily. In 2009, there were 57 760 new cases of kidney cancer and 12 980 estimated deaths from this disease [6]. The previous paradigms in urology for the treatment of renal masses did not support the use of renal biopsy, due to high false-negative rates. However, percutaneous renal tumor sampling (either with fine needle aspiration cytology or core biopsy) has become part of the algorithm for management of renal masses [2], especially in elderly patients with comorbidities. Furthermore, it is performed at the time of percutaneous renal ablative therapies to confirm the diagnosis.

Currently, the diagnosis and treatment of small renal masses has been evolving with the advent of new and improved imaging modalities as well as advances in immunohistochemical staining and molecular profiles. Historical series have estimated the incidence of immediate postbiopsy subclinical hematomas to be 91%. A recent series reports the incidence of postbiopsy hemorrhage (subcapsular and perinephric) to be lower (38.4%, 28 of 73) when 18G core needle biopsies are performed [7]. All hemorrhagic complications were managed conservatively; no embolization or blood products were required in this series [7].

Percutaneous cryotherapy/radiofrequency ablation

Numerous studies report 2- and 5-year data gathered subsequent to computed tomography (CT)-guided percutaneous ablative therapies with either cryoablation or radiofrequency ablation [8–13]. Most postablation CT/magnetic resonance imaging (MRI) scans are performed immediately after removal of the probes. Therefore, these postablation scans may not be a sensitive test for postoperative hemorrhage. Nonetheless, the incidence of acute postoperative hemorrhage ranges from 0.9% [14] to 49% [11]. This large variation is possibly due to the different authors' definitions of postoperative hemorrhage and the large time delay involved in performing postoperative scans. Cryoablation, as compared to radiofrequency ablation, has been associated with an increased risk of hemorrhage due to lack of thermal coagulation (Figure 30.1). In both the series reported by Georgiades *et al*. [11] and Hafron and Kaouk [14], patients were treated with conservative management. Georgiades *et al*. reported that 15 of 51 (29%) patients developed small asymptomatic perirenal hematomas and 10 of 51 (20%) developed large painful perirenal hematomas [11]. For patients undergoing percutaneous ablation, transfusion rates ranged from 0% to 4% and no patients required renal angioembolization [10,11].

Clayman *et al*. reported that tumor size directly correlated with incidence of bleeding. Tumors with a median size of 4.2 cm were associated with increased rates of postablation hemorrhage when compared to tumors with a median size of 2.6 cm ($P > .05$) [13]. When only a single probe is used, the rate of bleeding decreases to 0%. The use of multiple probes increases the degree of renal trauma and, hence, the incidence of bleeding complications [13].

Percutaneous nephrolithotomy

Despite the fact that percutaneous renal surgery is associated with lower morbidity, it is not without its complications [15, 16]. Lang performed a large multiinstitutional survey of patients undergoing PCNL. The overall complication rate was reported to be 26% [17]. The complication rates had a direct correlation with experience, which decreased from 61% to 3.7% with an increase in the level of experience [18].

The initial series of PCNL reported an 11% incidence of postoperative transfusions [19]. Lang, in 1987, reported the results of a survey of 62 institutions with a transfusion rate of 0.43% in patients undergoing PCNL [17]. In 2007, a study from the University of Western Ontario reported a post-PCNL transfusion or embolization incidence of 0.8% [18]. Stoller *et al*. reviewed risk factors associated with blood transfusions post PCNL and reported an association with multiple punctures, renal pelvic perforation, inexperience, preoperative anemia. and total blood loss [20].

Some authors have postulated that balloon dilators could decrease the risk of hemorrhage associated with PCNL. Recently, Wezel *et al*. compared two series of rigid dilations and balloon dilations and also performed a literature review. The authors found no difference in transfusion rates between the two techniques [21].

Laparoscopic partial nephrectomy

The majority of the literature regarding the complications of renal surgery focuses on the comparison of open to laparoscopic techniques. When evaluating the hemorrhage associated with laparoscopic renal surgery, it is important to keep it in perspective, because authors define the term "hemorrhage" in multiple ways. For example, a hemorrhage that requires a blood transfusion differs significantly from a hemorrhage that requires

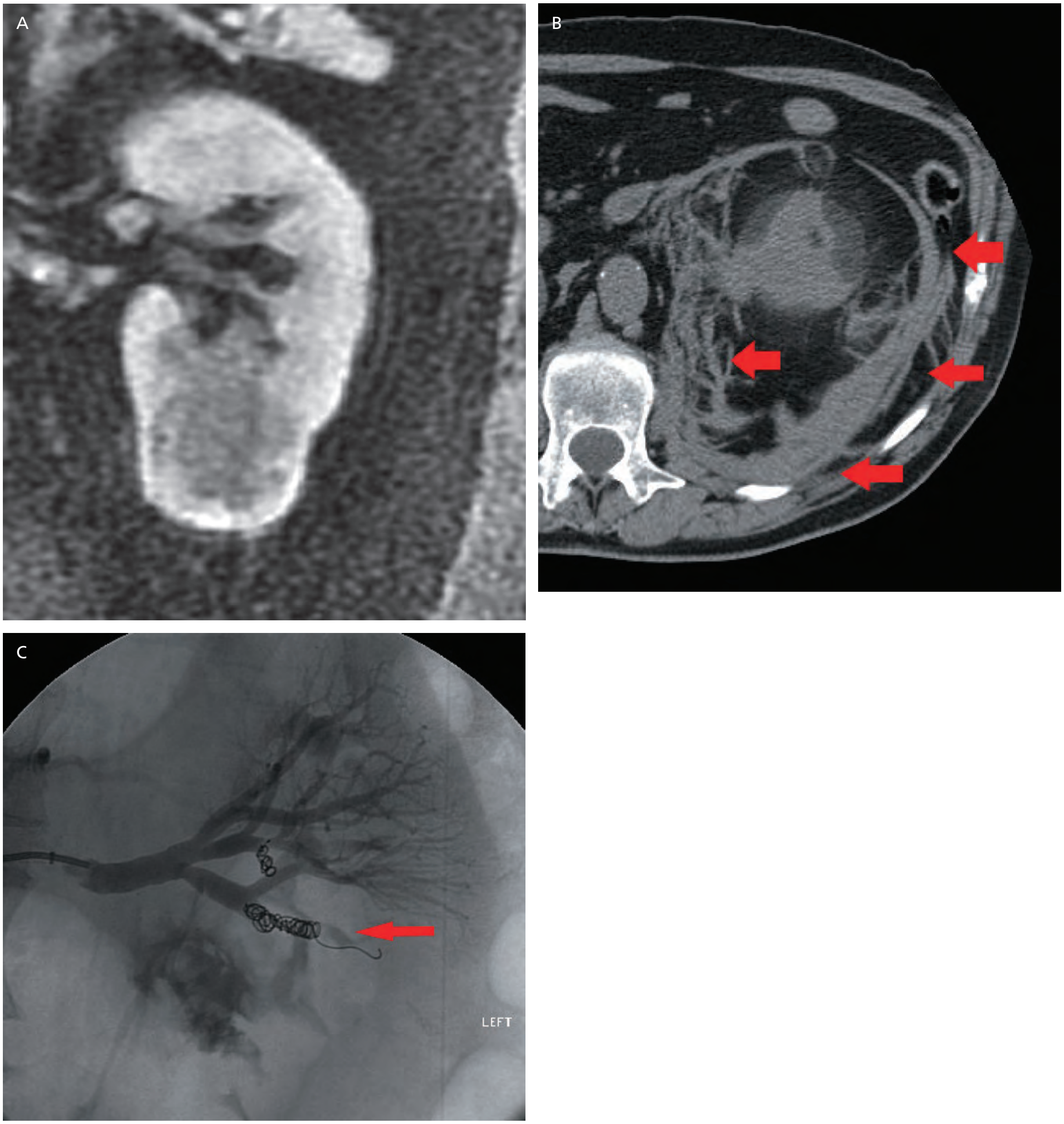

Figure 30.1 (A) Coronal reconstruction of lower pole renal mass. (B) Postprocedural CT scan of a patient with active hemorrhage after treatment of a 4-cm right lower pole renal mass with multiple cryoablation probes (arrows). (C) Postrenal angioembolization using coils (arrow).

reoperative management or embolization. Therefore, it is difficult to compare series. According to a review by Uzzo and Novick, the incidence of hemorrhage in the open series ranged from 1.4% to 7.9% [22].

An early LPN series from the Cleveland Clinic reported a 9.5% (19 of 200) perioperative incidence of hemorrhage requiring blood transfusions [23]. Patients with immediate hemorrhaging postoperatively were managed conservatively 2% (4 of 200), and delayed hemorrhaging occurred in 4% (8 of 200) of the patients. The Cleveland Clinic's most recent series of 800 cases illustrates the decrease in the incidence of complications associated with the procedure. Specifically, incidence of hemorrhage requiring surgical or radiologic intervention decreased to 2.1% of patients. The authors also noted a direct correlation between an increase in size of the lesion and the incidence of hemorrhage [24].

Management

Venous hemorrhage

Venous bleeding as the result of PCNL is usually self-limiting. During the procedure, the Amplatz sheath may tamponade the bleeding. However, if visualization cannot be maintained by placement of a sheath and/or removal of the clots, then the next step should be placement of a large 24F re-entry nephrostomy tube, which is then clamped to allow for clotting and hemostasis.

If conservative management fails, then a Kaye tamponade balloon catheter (Cook Medical Inc, Bloomington, IN, USA) can be used [25, 26]. The Kaye catheter tamponades the nephrostomy tract, but also effectively drains the renal pelvis and maintains ureteral access [25, 26]. The Kaye balloon must be positioned so that it occludes the bleeding vessel(s). If a Kaye balloon is not available, then a Council-tip catheter can be inflated in the renal parenchyma to tamponade the venous bleeding [27].

Perinephric hematoma

Post PCNL, a perinephric hematoma is a common finding. Extracorporeal shock-wave lithotripsy (ESWL) prior to PCNL increases the risk for developing a perinephric hematoma, as well as after LPN. A perinephric hematoma is usually clinically insignificant; however, if the hematocrit continues to decrease postoperatively, then a significant perinephric hematoma should be suspected despite clear urine output from the nephrostomy tube or voided specimens. The diagnosis can be confirmed with a triphasic abdominal CT scan to distinguish it from urinary leak. Initial management should consist of transfusion of crystalloids and blood products. If conservative measures fail, then renal angiography and superselective embolization should be performed in an attempt to identify and embolize the bleeding arterial branches. Once the hematoma liquefies and if the patient is symptomatic, then a percutaneous drain could be placed. In some cases, a return to the operating room for open exploration could be warranted.

Arterial hemorrhage

Postoperatively, patients can present with acute or delayed hemorrhage. This is usually exacerbated by strenuous activity and/or restarting anticoagulation therapy. Two large series have reported that patients who have undergone a LPN present with delayed hemorrhage at a median of 12 [28] and a mean of 17 [29] days post procedure.

Postoperative hemorrhage may present acutely with gross hematuria, dizziness, and/or hypovolemic shock. After stabilization with crystalloids and blood products, patients should undergo renal angiography and superselective embolization. The first reported use of renal artery embolization to control hemorrhage was in 1973 by Bookstein *et al*. [30]. The rate of postoperative hemorrhage requiring angioembolization has been consistent at 0.8–1.3% throughout the last 20 years in patients undergoing PCNL [31, 32]. With respect to LPN, Singh and Gill reported a 1.7% incidence of patients requiring embolization for treatment of postoperative hemorrhage [28]. The most common findings on angiography are arteriovenous fistulas, pseudoaneurysms, and lacerated renal segmental arteries (vessel cut-off) (Figure 30.2) [31, 32] (Further details of arterial embolization are described in Chapter 119.).

A recent publication from the University of California San Francisco group described its experience treating renal trauma [33]. A clinical success rate of 85% was achieved with selective embolization in patients with grade I–IV renal trauma after conservative management had failed. In a multiinstitutional review of 10 sites, the success rate reached 90% (151 of 167) utilizing renal angioembolization as a therapeutic intervention in the treatment of renal trauma [33]. Grade V renal trauma still requires surgical exploration.

In a series of 4695 patients who underwent PCNL for various indications, 1.2% postoperatively required angioembolization [32]. Also, similar data were obtained for patients undergoing LPN; 1.89% (7 of 370) [29]. Currently, there are no strict indications for renal angiography post PCNL. At our institution, when postoperative patients present with gross hematuria with clots, hypotension, or decreasing hematocrit that does not respond to conservative management, they are referred for angiography and possible embolization.

Conclusions

Postoperative renal hemorrhage is a well-known complication of minimally invasive renal procedures. It is important that patients are advised of this risk and that urologists be cognizant of management protocols. The majority of hemorrhagic complications can be managed with conservative measures and selective renal angioembolization. It is very rare to perform exploratory laparotomy and nephrectomy for failed renal angiographic management of postoperative hemorrhagic complications.

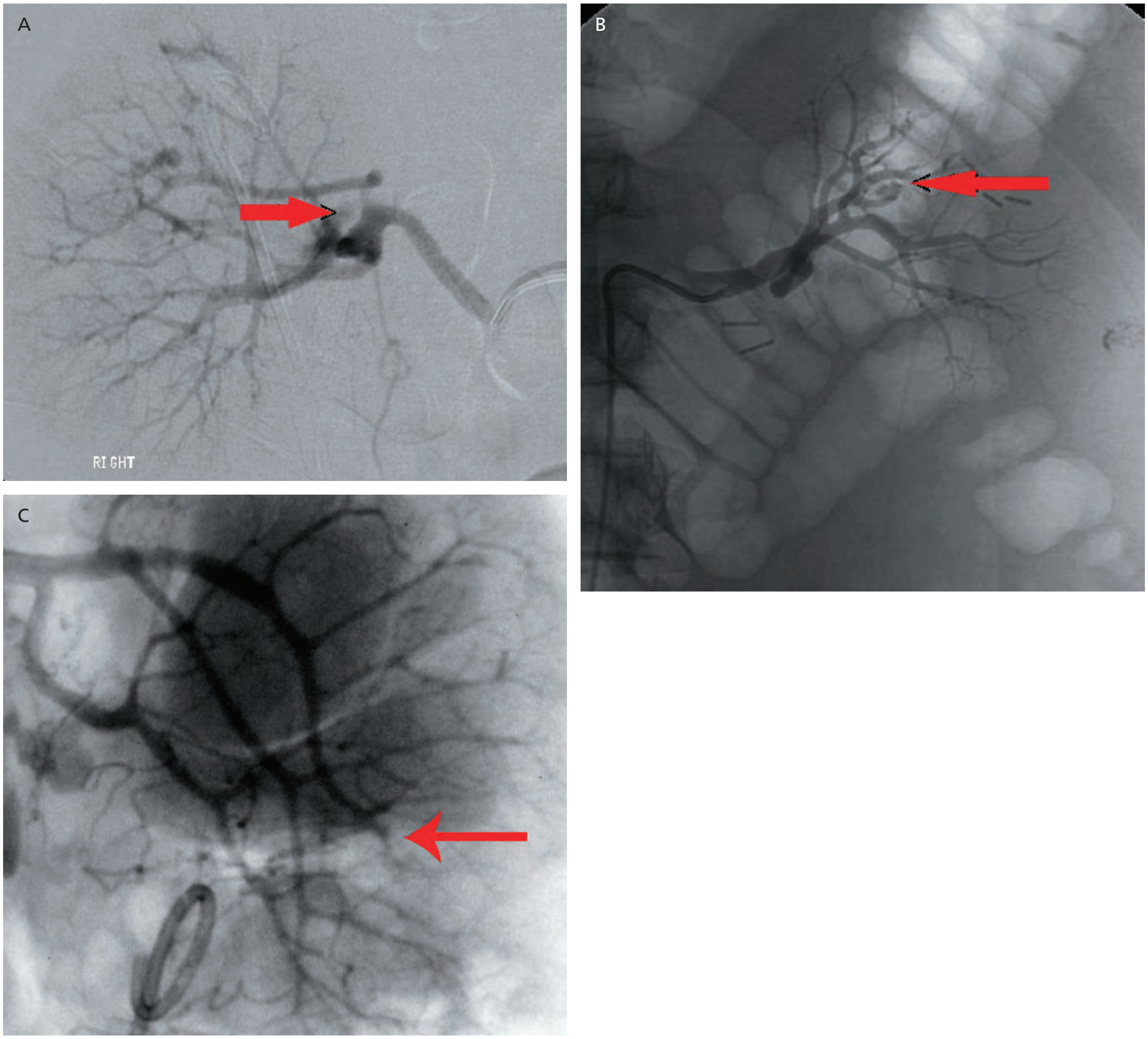

Figure 30.2 Renal angiography. (A). Arteriovenous fistula characterized by early filling of the main renal vein (arrow). (B) Pseudoaneurysm after a partial nephrectomy (arrow) (C) Lacerated renal artery branch (arrow; vessel cut off).

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CHAPTER 31

Diagnosis and Management of Thoracic Complications of Percutaneous Renal Surgery

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Introduction

Percutaneous renal surgery has evolved significantly since the first percutaneous nephrolithotomy (PCNL) was reported by Goodwin *et al*. in 1955 [1]. While the management of large and complex stone disease remains the most common application for percutaneous renal surgery, the approach is also well-suited for the minimally invasive treatment of ureteropelvic junction obstruction, select upper tract urothelial carcinomas, and ablative therapy for small renal masses. As a minimally invasive treatment modality, percutaneous renal surgery is associated with a unique set of complications, including bleeding from or damage to the kidney, and injury to nearby structures. The type of percutaneous renal access determines in part the risk of surrounding tissue injury. Solid organs, such as the spleen and liver, can be injured with an upper pole access, which usually manifests with significant bleeding. A retrorenal portion of the colon can predispose to a colonic injury. Finally, injury to the pleura and lung can occur, usually in the setting of upper pole or supracostal renal access. Thoracic complications, which include pneumothorax, hydrothorax, hemothorax, and nephropleural fistula, will be the focus of this chapter.

Injury to the lung and pleura can occur with access through any renal calyx, however the incidence increases significantly with upper pole and supracostal access. Renal anatomy determines whether access to a particular calyx will require a supracostal or subcostal approach. Many upper pole renal access sites are supracostal, although a small number may be subcostal, particularly in kidneys situated more caudally. Similarly, access into a mid or lower pole calyx may be supracostal in more cephalad kidneys. In some cases, subcostal access into a mid or lower calyx that is situated relatively high in the retroperitoneum can traverse the diaphragm and pleura. As such, each individual patient's anatomy must be taken into consideration. The indications for supracostal or upper pole renal access are discussed in Chapter 16.

Thoracic complications

Thoracic complications include pneumothorax, hydrothorax, hemothorax, and nephropleural fistula, with the possibility of more than one of these conditions coexisting. The incidence of these complications ranges from 0% to 18%, varying in part due to the type of renal access obtained. Table 31.1 lists the pleural complication rates of PCNL by series, including a description of reported complications. Pneumothorax can occur via the introduction of air into the pleural space while obtaining access or during the procedure, and to a lesser degree during nephrostomy tube removal. Alternatively, an injury to the lung can also result in a pneumothorax, although this complication is less commonly reported. In the case of injury to the lung parenchyma, a tension pneumothorax can develop.

Hydrothorax can occur when irrigation fluid or urine enters the pleural space along the nephrostomy tract or from diaphragmatic irritation with a reactive effusion. Picus *et al*. proposed two theories to explain the evolu-

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Table 31.1 Thoracic complications following supracostal percutaneous nephrolithotomy.

	Total number of patients/ renal access sites	Site of access	Number of pleural complications (%)	Description of complication
Picus *et al*. [2]	50	Supracostal	6 (12%)	Large pleural effusion (n = 4) Hydropneumothorax (n = 2)
Golijanin *et al*. [3]	115	Supracostal	10 (8.7%)	Large pleural effusion (n = 4) "Significant" atelectasis (n = 6)
Stening and Bourne [4]	21	Supracostal	0 (0%)	None
Kekre *et al*. [5]	102	Supracostal	10 (9.8%)	Hydrothorax (n = 7) Hydropneumothorax (n = 2) Pneumothorax (n = 1)
Munver *et al*. [6]	98 202	Supracostal Subcostal	7 (7.1%) 1 (0.5%)	Hydro/hemothorax (n = 5) Nephropleural fistula (n = 2) Pneumothorax (n = 1)
Gupta *et al*. [7]	62	Supracostal	7 (11%)	Blunting of CPA (n = 3) Hydrothorax (n = 3)
Radecka *et al*. [8]	22 63	Supracostal Subcostal	4 (18%) 0 (0%)	Pleural effusion (n = 2) Pneumothorax (n = 2)
Muzrakchi *et al*. [9]	57	Supracostal	1 (1.8%)	Atelectasis/elevation of hemidiaphragm (n = 1)
Netto *et al*. [10]	119	Supracostal and subcostal	2 (1.7%)	Pneumothorax (n = 1) Hydrothorax (n = 1)
Kim *et al*. [11]	63	Supracostal (n = 58) Subcostal upper pole (n = 5)	3 (4.8%)	N/A
Muslumanoglu *et al*. [12]	23 252	Supracostal Subcostal	2 (8.4%) 0 (0%)	Hydropneumothorax (n = 2)
Yadav *et al*. [13]	332	Supracostal	11 (3.3%)	Pleural effusion (n = 11)
Michel *et al*. [14]	315	Supracostal and subcostal	0 (0%)	None

CPA, costophrenic angle; N/A, not available.

tion of the pleural effusion after PCNL [2]. First, inadequate tamponade of the percutaneous nephrostomy tract combined with inadequate drainage of the kidney after the procedure can result in a fluid collection. Second, failure to seal the tract with a working sheath during the procedure can allow irrigant and urine to freely efflux into the pleural space.

Hemothorax is usually the result of an injury to the intercostal artery, diaphragm, renal parenchyma, or renal vasculature, with subsequent bleeding into the pleural space. Similar to the pathophysiology of hydrothorax, bleeding from the kidney can also track along the nephrostomy tube tract into the pleural space. Romero *et al*. reported two cases of hemothorax after percutaneous

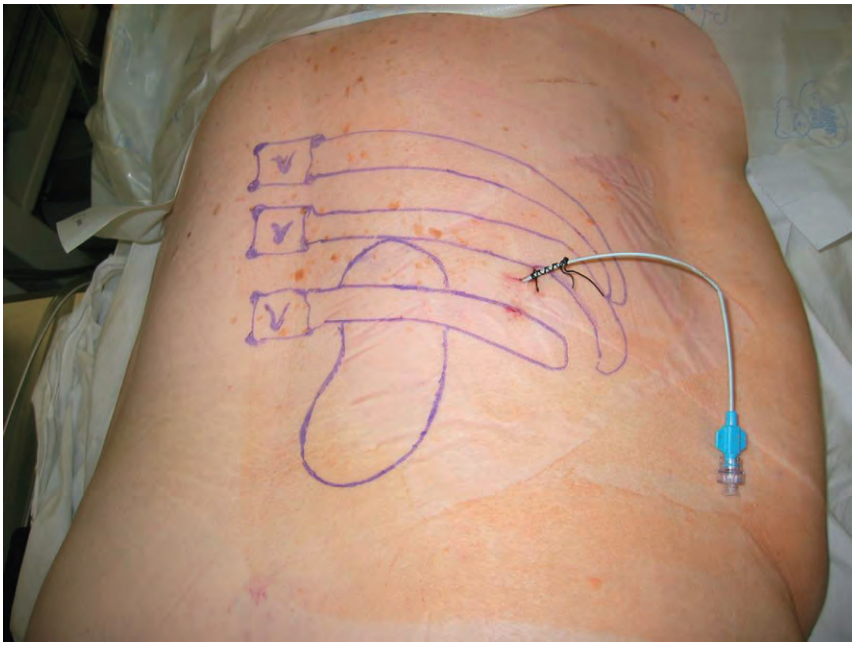

Figure 31.1 Upper pole renal access placed in preparation for percutaneous nephrolithotomy. The nephrostomy tract is placed in a supracostal position above the 12th rib, lateral to the midscapular line.

renal cryoablation of a renal mass [15]. The authors suggest the cause of these complications may have been injury to the phrenic or subcostal vessels, or a local irritative process from direct contact between a retroperitoneal hematoma and the posterior diaphragm.

Nephropleural fistula, the persistent drainage of urine from the renal collecting system into the pleural space, is similar to hydrothorax. While hydrothorax usually presents early in the postoperative course due to fluid collection during or shortly after the procedure, a nephropleural fistula often occurs later after nephrostomy tube removal. Development of a nephropleural fistula can be associated with distal collecting system obstruction.

Anatomy

An understanding of the diaphragmatic, pleural, and lung anatomy is critical to minimize thoracic complications. The diaphragm is attached to the inferior border of the 12th rib, the transverse process of the first lumbar vertebrae, and the anterior surfaces of the upper lumbar vertebral bodies. As a result, percutaneous access between the 11th and 12th ribs typically involves traversing the diaphragm.

The lung is enveloped by two layers of pleura. The visceral pleura is closely associated with the lung, and the parietal pleura covers the ribs, diaphragm, and mediastinal structures. The pleural space lies between the visceral and parietal pleura, with only a small amount of fluid occupying this space. The lower limit of the parietal pleura courses over the 12th rib obliquely, such that the lateral half of the rib is not covered by pleura. Percutaneous renal access over the lateral half of the 12th rib is preferable to avoid pleural violation. In the midscapular line, the visceral pleura extends to the 10th rib. Both the visceral and parietal pleura rise with expiration, and therefore percutaneous access lateral to the midscapular line below the 10th rib during expiration should serve to avoid the visceral pleura. Figure 31.1 demonstrates upper pole, supracostal access above the 12th rib. The nephrostomy tube was placed lateral to the midscapular line.

Hopper and Yakes evaluated the risk of lung and solid organ injury during posterior intercostal renal access [16]. Patients were imaged with computed tomography (CT) during full inspiration and expiration, and a line was drawn on the CT image from the upper pole of the kidney to the upper margin of the 11th and 12th ribs. The authors found that the phase of respiration had little effect on the relationship between the upper pole calyx and the 11th and 12th ribs in the prone and supine positions. When access above the 12th rib was considered, 29% of punctures on the right and 14% on the left would have traversed the lung if performed during full expiration. These percentages increased to 86% on the right and 79% on the left if the puncture was performed during full inspiration.

Risk factors for thoracic complications

Supracostal percutaneous renal access can provide an optimal approach for complex stones, but is associated with a higher risk of thoracic complications as compared to a subcostal access. In a review of 464 patients who underwent upper pole PCNL, the incidence of chest complications in the supracostal group was 15.3%, with 5.3% requiring drainage of the pleural space. In contrast, the incidence was 1.4% in the subcostal group, with only 0.3% requiring drainage [17]. Similarly, Radecka *et al*. found a substantially higher rate of thoracic complications with the supracostal approach [8]. The authors also noted that pain associated with respiration was significantly higher in the supracostal group (32%) compared to the subcostal group (5%), which may potentially increase the risk of postoperative respiratory complications. Another study comparing 103 patients undergoing PCNL via a supracostal approach, and 39 patients via a subcostal approach, found a lower overall complication rate with the supracostal approach [18]. The incidence of chest complications was similar, with one case of hemothorax (1%) in the supracostal group and one case of pneumothorax (2.6%) in the subcostal group. Obesity was a major contributing factor in the overall complication rate, with the supracostal hemothorax occurring in an obese patient. Yadav *et al*. reported a 10-fold higher incidence of chest complications in patients who received a supracostal approach as compared to a subcostal approach [13]. While the supracostal approach may be associated with a higher thoracic complication rate, it is often preferred as a successful procedure is more likely. The authors reported that the majority of cases requiring supracostal access involved complicated stones, such as staghorn calculi or impacted upper ureteral stones. While the thoracic complication rate is reportedly lower with a subcostal approach, patients with complex stones are likely to benefit from improved stone clearance associated with a supracostal approach.

The incidence of thoracic complications also increases when a more cephalad intercostal space is used for access. Munver *et al*. reviewed 240 patients who underwent percutaneous renal surgery, including 98 patients with supracostal access [6]. Of these patients, access was obtained in the 10th intercostal space in 26 patients and in the 11th intercostal space in 72 patients. Thoracic complications occurred after eight procedures, of which seven were via a supracostal access. Of these seven thoracic complications, six occurred in the 10th intercostal space group and one in the 11th intercostal space group. The authors concluded that access via the 10th intercostal space is associated with a 16-fold higher thoracic complication rate when compared to the 11th intercostal space, and a 46-fold higher rate when compared to subcostal access. In another series, Shaban *et al*. reported two thoracic complications in a series of 30 patients undergoing percutaneous renal surgery via a supracostal approach [19]. Both of these complications occurred in patients with 10th intercostal space access. Based on these findings, the authors recommended that access above the 11th rib should be performed only by those with significant experience and only when the benefits of this access outweigh the risks.

Intraoperative technical factors may also increase the risk of thoracic complications. Young *et al*. reported a series of 24 patients who underwent PCNL via a supracostal access [20]. One patient developed a large hydrothorax requiring drainage of 1500 mL of fluid. A working sheath had not been used during this procedure, and the authors suggested that use of a working sheath may have prevented this complication.

Renal access may be obtained either by a radiologist or urologist, depending on the urologist's training and an institution's protocol. Watterson *et al*. reviewed access-related complications during a series of percutaneous nephrolithotomies and found no difference in the complication rate when the access was performed by a radiologist or urologist [21].

In summary, a more cephalad access site increases the risk for thoracic complications. Renal access above the 11th rib is associated with a marked increase in complication rates. Technical factors may also contribute to the development of complications, such as avoiding use of a working sheath. The sheath should be advanced into the renal collecting system to decrease efflux of irrigation into the retroperitoneum and pleural space. While it is difficult to accurately measure the volume of irrigant infused, an obvious discrepancy between the inflow and outflow of irrigant should alert the surgeon to a potential problem. In this case, fluoroscopy can be used to inspect the costophrenic angle to evaluate for hydrothorax.

Diagnosis

The diagnosis of pleural injury is ideally made intraoperatively, at which time it may be treated expeditiously and with minimal patient discomfort. Alterations in ventilatory parameters may indicate pleural violation and should prompt fluoroscopic evaluation to search for a pneumothorax or hydrothorax. Even in the absence of ventilatory changes, fluoroscopic evaluation of the lung and costophrenic angle should be performed at the end of the procedure. This complication can also be diagnosed in the postoperative period either based on routine chest imaging or the development of signs and symptoms.

Another intraoperative indication of a thoracic complication is significant bleeding through the nephrostomy tract. While this may occur from a renal vascular injury, the surgeon should be suspicious of an intercostal artery injury in cases using a supracostal approach. Figure 31.2A shows bleeding from a supracostal renal access sheath during PCNL in a patient who developed a hemothorax from intercostal artery injury. Figure 31.2B shows the poor visualization during nephroscopy due to extensive bleeding.

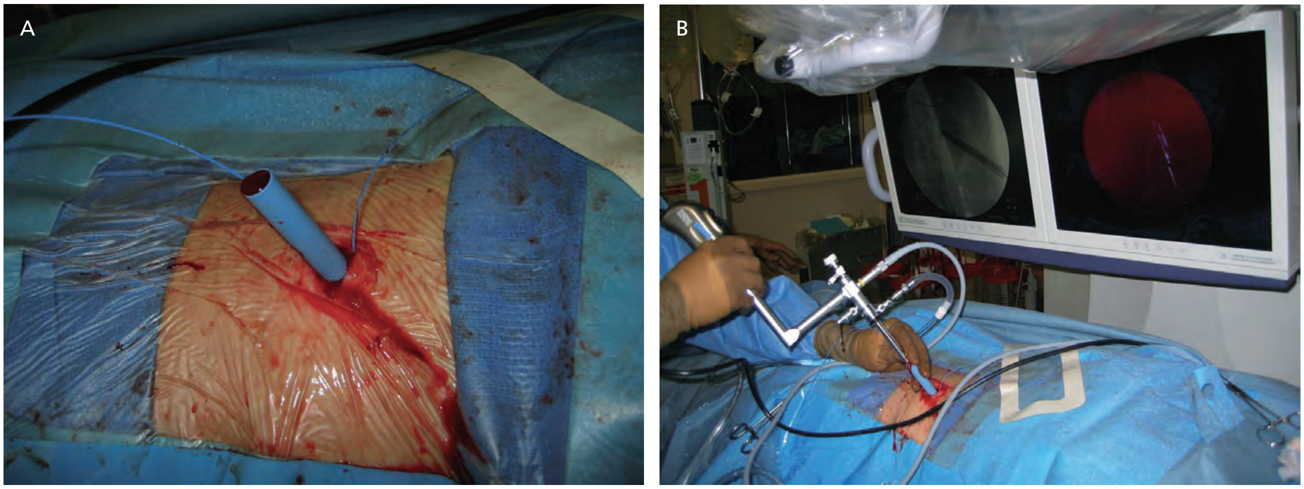

Figure 31.2 (A) Hemorrhage following injury to an intercostal artery as elicited by bloody output from an access sheath placed via a supracostal access tract. (B) Compromised nephroscopy due to excessive bleeding. Left screen shows cephalad angulation of nephroscope; right screen shows the obscured view due to bleeding.

Some surgeons advocate chest X-ray (CXR) after all supracostal percutaneous renal procedures. On a posterioanterior CXR, a meniscus is visible when 175–200 mL of fluid is present in the costophrenic sulcus [22, 23] and the hemidiaphragm is obscured with 500 mL [23]. Chest CT can also be used to detect a pleural fluid collection or pneumothorax, although it may also demonstrate clinically insignificant pathology due to its high sensitivity [24]. Figure 31.3 shows a right pleural fluid collection after supracostal PCNL. Ogan *et al*. compared the sensitivity of CXR, chest CT, and intraoperative chest fluoroscopy in detecting hydropneumothorax [24]. Fluoroscopy was performed at the completion of the PCNL procedure to evaluate for pleural fluid, and tube thoracostomy was performed if indicated. All patients underwent CXR in the recovery room. CT was performed in the postoperative period to evaluate for residual stone burden, with the CT imaging including the lung bases as per the radiology protocol. Of the 104 percutaneous renal accesses performed in the study, 58% were supracostal. Fluoroscopy detected pleural fluid in one patient (1%), CXR detected hydrothorax in 8%, and chest CT detected hydrothorax in 38%. With CT diagnosis serving as the reference standard, intraoperative fluoroscopy had a false-negative rate of 59.6% and a 0% false-positive rate. Similarly, postoperative CXR was associated with a 48.4% false-negative rate and 2.6% false-positive rate. An intervention for hydropneumothorax was necessary in seven patients, all of whom had undergone a supracostal access. Interventions outside of the operating suite were performed for a large hydropneumothorax or the presence of symptoms; however, no interventions were performed solely on the results of the postoperative CXR. The authors concluded that routine CXR in the recovery room is unnecessary, and the development of symptoms or the findings of a large effusion on CT may warrant intervention. Intraoperative fluoroscopy and postoperative CXR, when indicated, are usually sufficient to diagnose a thoracic complication. Renal scintigraphy has been described to aid in the diagnosis of a case of urinothorax after PCNL, though the clinical application of this modality is limited [25].

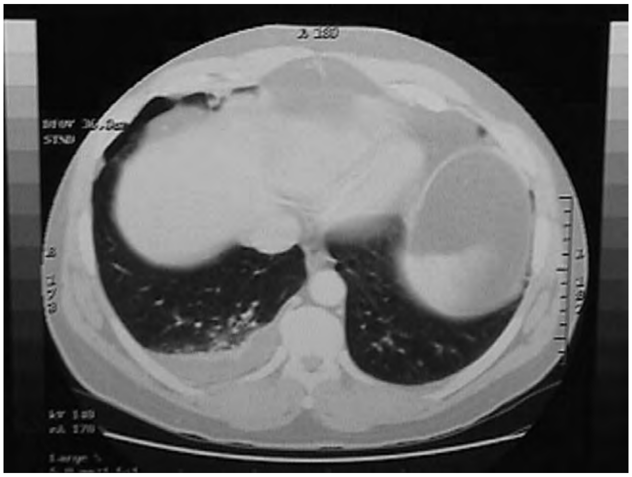

Figure 31.3 Chest CT scan demonstrating right hydrothorax after supracostal percutaneous nephrolithotomy. Note fluid layering in the right hemithorax (photograph courtesy of Dr Glenn Preminger).

In the postoperative period, the diagnosis of a thoracic complication is often based on the patient's symptoms. Complaints may include shortness of breath or chest pain, with objective findings including increasing oxygen requirement and decreased breath sounds over the affected lung field. In one series of 102 supracostal PCNL procedures, 10 patients were diagnosed with thoracic complications. Four patients were diagnosed intraoperatively before extubation, three were diagnosed in the recovery room based on oxygen desaturations, and three developed shortness of breath and tachypnea several hours later after transfer to the surgical floor [5].

Nephropleural fistula is a unique complication, often presenting later in the postoperative course after nephrostomy tube removal. Lallas *et al*. described a series of 375 patients undergoing percutaneous renal surgery, including supracostal access in 26% of the procedures [26]. Four patients were diagnosed with nephropleural fistula after nephrostomy removal, two of which presented immediately. The diagnosis was made on the basis of a retrograde pyelogram. In cases of persistent drainage from a chest tube placed for hydrothorax, a nephropleural fistula should be considered. Patients with signs or symptoms of pulmonary complications, either early in the postoperative period or after nephrostomy removal, should initially be evaluated with physical exam and CXR. Based on these findings, a retrograde pyelogram may be necessary to document a fistulous connection between the collecting system and pleural space after supracostal PCNL (Figure 31.4). Persistent drainage suggests the possibility of distal ureteral obstruction, which can also be assessed with a retrograde ureteropyelogram.

Prevention

Prevention of thoracic complications begins with an assessment of the anatomic relationship between the kidney and pleural space, and a determination of the appropriate access site. As described earlier, the parietal pleura courses over the 12th rib in an oblique fashion, such that the lateral half of the rib is not covered by pleura. At the beginning of the procedure, fluoroscopic evaluation can assist in identifying the inferior pleural margin. Biplanar fluoroscopy may provide superior visualization of the anatomic relationship between the kidney and pleural space, and decrease the risk of complications [9]. Supracostal access should be performed lateral to the midscapular line to minimize injury to the pleura. The needle should be advanced along the upper margin of the rib during shallow breathing or during the expiratory phase. Needle passage along the inferior margin of the rib risks injury to the intercostal neurovascular bundle, which can result in significant bleeding. Some authors have recommended calyceal entry during inspiration to displace the kidney caudally [27].

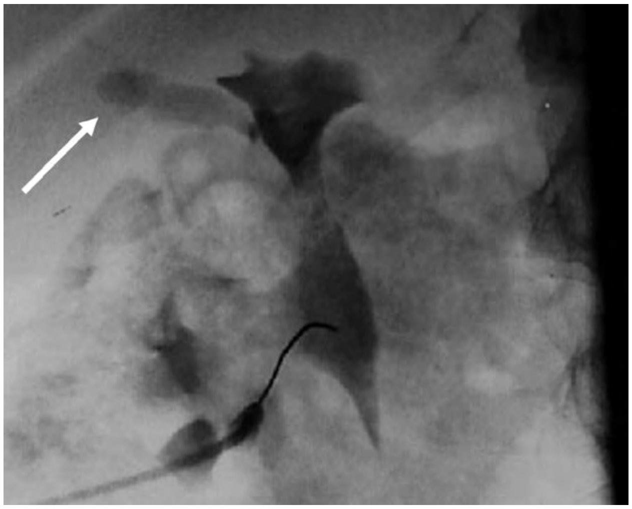

Figure 31.4 Nephrostogram showing a fistulous communication between the collecting system and the pleura. Arrow points to the nephropleural fistula (photograph courtesy of Dr Glenn Preminger).

Pedro *et al*. describe a technique of renal displacement to allow the renal access to be obtained more caudally than would otherwise be possible [28]. If the targeted calyx is above the 11th rib, the authors place an extra access site into a mid–posterior calyx to help displace the kidney caudally. This access site can also be used for postoperative drainage. A similar recommendation, using either saline or carbon dioxide, was described by Romero *et al*. to minimize the risk of hemothorax during percutaneous renal mass cryoablation [15]. The injection of saline or carbon dioxide displaced the kidney caudally away from the diaphragm. Displacing the kidney in this manner also minimizes diaphragmatic irritation from extravasated blood products.

Once access has been obtained and the tract dilated, an access sheath should be utilized to minimize extravasation of irrigant into the retroperitoneum and pleural space. In the event that the parietal pleura is traversed by the needle, the use of an access sheath can often prevent this from evolving into a thoracic complication. The amount of irrigant used during the procedure should be monitored, although a precise measurement is difficult. If the inflow of irrigant is significantly more than the measured outflow, the possibility of extravasation into the pleural space should be considered, and the chest fluoroscopically evaluated.

Postoperative renal drainage after percutaneous nephrolithotomy is based on the site of access, amount of stone burden, degree of collecting system trauma, plan for a second-look procedure, and surgeon preference. Blood clots or stone fragments that may pass into the ureter can cause ureteral obstruction, potentially resulting in a nephropleural fistula. In many patients, a nephrostomy tube is left in place for a minimum of 24 h following the procedure. If a nephrostomy tube is left at the end of the procedure, the appropriate position within the collecting system is of importance. An antegrade nephrostogram can help to ensure that the catheter is well-positioned. Shaban *et al*. described a case of a nephropleural fistula 2 days after PCNL in a patient with dyspnea, chest pain, and fever [19]. An antegrade nephrostogram demonstrated one side-hole of the nephrostomy tube to be outside of the kidney, with extravasation of urine into the pleural space. The patient was managed with a thoracostomy tube and an internal ureteral stent.

Kim *et al*. described the use of a lower pole nephrostomy tube for drainage after percutaneous renal surgery through an upper pole access site [11]. The 62 patients included in the study underwent upper pole renal access, with the upper pole access site left tubeless at the end of the procedure. Patients were included only if they had minimal or no stone fragments at the end of the procedure. A subcostal nondilated access site was utilized for the nephrostomy tube, providing drainage and secondary access if needed. The authors suggest that this technique minimizes patient morbidity.

Thoracic complications following tubeless PCNL will be addressed at the end of the chapter.

Management

One of the most important tenets of the management of thoracic complications is early diagnosis when possible. Patients with supracostal access should be regarded as high risk for thoracic complications. At the conclusion of each percutaneous renal surgery procedure, the lung field and costophrenic sulcus should be closely evaluated with fluoroscopy. Pneumothorax, hydrothorax, and hemothorax may be noted at this time, and a thoracostomy tube may be placed while the patient remains anesthetized.

A relatively small pleural effusion or pneumothorax noted on intraoperative fluoroscopy, in the absence of any changes in ventilatory parameters, may be managed conservatively or with simple needle aspiration. When a large pleural effusion or pneumothorax is noted intraoperatively, a thoracostomy tube should be placed. Ogan and Pearle describe the intraoperative placement of a chest tube using fluoroscopic guidance [29]. A Chiba needle is inserted along the posterior axillary line under fluoroscopic guidance until it is seen in the fluid-filled pleural space. A nitinol wire is then passed through the needle, and a wire guide exchange set can be used to replace the nitinol wire with a larger caliber guidewire. A 10F nephrostomy tube is passed over the guidewire, positioned at the base of the pleural cavity, and the tube is connected to a pleur-evac set-up. If bloody fluid is encountered, a larger tube should be used. The authors state that the tube can usually be removed within 24–48 h when drainage has resolved.

In the postoperative period, the management of hydrothorax depends on the size of the effusion and the degree to which the patient is affected. Minimal blunting of the costophrenic angle can usually be managed conservatively [7]. Large or symptomatic effusions should be treated with drainage of the pleural space. Needle aspiration can relieve a smaller effusion, but tube thoracostomy should be used for larger effusions. The thoracostomy output and CXR are monitored, and with resolution of drainage and the effusion, the tube can be removed. Typically, the average duration of chest drainage is 3–4 days [7]. If a second-look PCNL is planned, the thoracostomy tube should be left in place until after this procedure is completed [29].

As described previously, nephropleural fistula can occur much later in the postoperative course. When suspected, a retrograde pyelogram can be diagnostic. If a fistulous connection is seen, an indwelling internal ureteral stent can be placed at that time. In most cases, decompression of the collecting system with a stent and the pleural space with a thoracostomy is indicated [26]. If a stent had been placed at the time of the percutaneous renal surgery, urine reflux from the bladder may be a contributing factor for persistent drainage. The bladder should remain decompressed with a urethral catheter until the thoracostomy tube output decreases.

A diagnostic and treatment algorithm can be proposed based upon the preceding discussion. Intraoperatively, the ipsilateral lung field and costophrenic angle should be assessed fluoroscopically, especially in patients undergoing supracostal or upper pole renal access. If a large effusion is noted, the effusion can be drained, with a thoracostomy tube left in place if a significant amount of fluid is obtained. If the costophrenic angle is partially obscured without a large pleural effusion, the patient can be clinically monitored or receive a CXR in the recovery room [30]. In the postoperative period, signs or symptoms that raise suspicion for a thoracic complication should prompt a CXR. If a clinically significant pleural effusion or large pneumothorax is encountered, a tube thoracostomy should be placed at that time. Alternatively, if the effusion is small and is not consistent with a hemothorax, then needle drainage alone is sufficient. In the event that the effusion is bloody, a larger tube thoracostomy would provide sufficient drainage. In the patient who develops signs or symptoms of a thoracic complication later in the postoperative course, especially in the setting of recent nephrostomy removal, a nephropleural fistula should be considered. The first diagnostic test is a CXR, and if a pleural effusion is noted, a retrograde pyelogram should be performed. If the retrograde pyelogram demonstrates a fistulous connection between the renal collecting system and the pleural space, an indwelling ureteral stent is placed, usually in conjunction with a thoracostomy tube. A pneumothorax immediately after nephrostomy removal is often small, resulting from the introduction of air into the pleural space during tube removal. If symptoms are minimal and the pneumothorax is small, no other treatment is necessary. Alternatively, tube thoracostomy may be considered.

A unique set of complications can develop in the setting of an undrained or poorly drained hemothorax, including empyema and fibrothorax. These complications are well-described in the general surgery literature as sequelae of traumatic hemothorax. A general or thoracic surgery consult should be obtained early in the course of a complex hemothorax to improve outcomes. Early evacuation of a hemothorax is critical to decrease the risk of these complications as well as minimize the invasiveness of the management protocol. The goal of early drainage is to prevent formation of loculations, which occur approximately 7 days after the initial injury [31]. If a retained hemothorax is noted after thoracotomy tube placement, a second thoracotomy tube may be placed. Some authors suggest that a trial of intrapleural streptokinase may be effective early in the course [31]. If a second thoracotomy tube fails to fully drain the hemothorax, thorascopic evacuation can be performed [32, 33]. Thorascopic evaluation is best performed within the first 5 days after injury to improve the success rate and minimize additional complications [32]. A poorly drained hemothorax can develop into an empyema, increasing the complexity of treatment. As the empyema evolves, a visceral "peel" develops, leading to parenchymal trapping [31]. Finally, fibrothorax can occur, which is characterized by diffuse pleural thickening and leads to respiratory compromise. Although rare, this complication is difficult to manage, often requiring surgical intervention with debridement [34].

Pediatric patients

Pediatric patients represent a unique population in the treatment of stone disease. More centers are gaining experience with pediatric PCNL and have accrued significant experience with complex stone disease. The indications for upper pole and supracostal renal access are similar in the adult and pediatric populations. El-Nahas *et al*. described 50 pediatric patients who underwent 60 PCNL procedures [27]. Supracostal access was obtained in 20 of the procedures and subcostal access in the remaining 40 procedures. There were no thoracic complications in any of the patients, and the overall complication rate between the two groups was similar. Stone-free rates were also comparable in each group.

Techniques to minimize the risk of thoracic complications in pediatric patients are similar to those in the adult population. These include avoiding the 10th intercostal space approach when possible, accessing the kidney over the lateral portion of the rib, and identifying the inferior pleural margin using fluoroscopy. While El-Nahas *et al*. report excellent results with pediatric supracostal PCNL, the report represents the experience of a high-volume pediatric stone center. Institutions with less pediatric stone experience may note higher thoracic complication rates, and this approach should be used with caution.

Tubeless percutaneous nephrolithotomy

Tubeless PCNL is gaining popularity as it is associated with decreased postoperative pain, analgesia requirement, and a shorter hospital stay. However, some surgeons are reluctant to consider tubeless PCNL when a supracostal access site is used. Shah *et al*. described 454 tubeless PCNL procedures using 535 renal tracts, of which 358 were supracostal [35]. The authors found that tubeless PCNL was not associated with more chest complications compared to standard PCNL in which a nephrostomy tube is left at the end of the procedure. Jou *et al*. caution surgeons to monitor for delayed complications, reporting a delayed pneumothorax 1 day after PCNL performed through the 11th intercostal space [36].

In summary, tubeless percutaneous nephrolithotomy is likely safe in appropriately selected patients, and with close attention paid to fluoroscopic evaluation of the lung field and costophrenic angle at the completion of the procedure.

Conclusions

Percutaneous renal surgery has gained in popularity for a variety of applications within the past decade. Surgeons have become more comfortable with the percutaneous treatment of complex stone disease. Many of these complex cases are best approached utilizing a supracostal access to increase success rates. While the supracostal access often offers a higher stone-free rate in these patients, it is also associated with a higher rate of thoracic complications. An appreciation for renal and pleural anatomy can help decrease the risk of these complications. Close radiographic surveillance of the lung field and costophrenic angle during the procedure can identify complications early, allowing prompt management that is more tolerable for the patient. In the postoperative period, the surgeon must be attuned to the signs and symptoms of thoracic complications, and be prepared to manage such complications in the event that they arise.

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CHAPTER 32

Bowel and Other Organ Injury during Percutaneous Renal Surgery

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Colon injury

Colonic perforation is a rare complication during percutaneous renal surgery, reported in about 1% of cases [1–6]. This low incidence is likely the result of the colon rarely being retrorenal (reported in approximately 0.6% of the general population [7, 8]). A retrorenal colon is most frequently noted on the left side and is most likely to be situated near the inferior pole of the kidney (Figure 32.1) [9]. Hopper *et al.*, in a study of 500 computed tomography (CT) scans of the abdomen, reported that the overall frequency of retrorenal colon in the supine patient was 1.9% [10, 11]. When 90 patients were studied in the prone position, a retrorenal colon was found in 10%. A puncture site laterally may increase the risk of colon injury. The position of the colon is usually anterior or anterolateral to the lateral renal border. Therefore, risk of colon injury usually exists only with a very lateral (lateral to the posterior axillary line) puncture.

Risk factors

Displacement of the colon posterior to the kidney increases the risk of colon perforation, and is seen in elderly patients with chronic constipation or patients with other causes of colonic distention, patients with previous major abdominal surgery (jejunoileal bypass, partial jejunoileal bypass), neurologic impairment, and institutional bowel resulting in an enlarged colon. Others at greater risk include thin female patients with little retroperitoneal fat, and patients with mobile kidneys, anterior calyceal puncture, previous extensive renal surgery [11, 12], horseshoe kidney and other forms of renal fusion or ectopia [13, 14], and kyphoscoliosis (Figure 32.2) [7, 15–18].

Ultrasound-guided renal percutaneous access can be performed in patients at increased risk of having a retrorenal colon [19]. A preoperative CT scan with the patient in the prone position is strongly recommended if there is any concern for colonic injury. For some, CT-guided access should be considered if the window of entry into the collecting system may be quite small [20].

Diagnosis

Prompt, early recognition of a colonic perforation is essential to limit serious infectious consequences. Colonic perforation should be suspected if the patient has intraoperative or immediate postoperative diarrhea or hematochezia, signs of peritonitis, or passage of gas or feces through the nephrostomy tract [21]. Otherwise, postoperative nephrostography before nephrostomy removal can reveal the presence of colonic contrast. Sepsis has been reported to occur in 0.6–1.5% of patients who undergo percutaneous stone removal [2, 22–24]. Antibiotic therapy, fluid resuscitation, and even the administration of pressors may be necessary to treat these patients. If the patient's condition does not improve with these measures, CT imaging is recommended to assess for unsuspected abdominal, retroperitoneal complications that contribute to sepsis, such as colonic perforation.

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Treatment

The majority of patients with colonic injuries can be treated without open surgical intervention if the penetration is retroperitoneal and the patient does not have peritonitis or sepsis [25]. An indwelling double-J stent is inserted, the nephrostomy tube withdrawn under fluoroscopic guidance into the colon (Figure 32.3), and a Foley catheter left in place in the bladder to maintain a low urinary pressure system. The patient should be given broad-spectrum antibiotics or triple antibiotic coverage and be on a low-residue diet. This allows the renal collecting system to heal and the medial colonic wall to close. After 5–7 days, if the colostogram or a retrograde pyelogram shows neither extravasation nor colonic communication with the collecting system, the Foley catheter is removed and the colostomy tube withdrawn but still kept as a drain outside the colon. After 2–3 days (7–10 in total), when the lateral colonic wall is expected to have closed, and if there is no evidence of a persistent nephrocolic fistula, the tube is then completely removed [3, 5–7].

In case of intraperitoneal colonic perforation, peritonitis, sepsis, or failed conservative management, open surgical exploration should be performed, and a colostomy is usually necessary.

Some authors have reported on the nonoperative management of a nephrocolic fistula that resulted from percutaneous nephrostolithotomy with adequate urinary and colon drainage, elemental diet, and antibiotic coverage. In 1983, Vallancien *et al*. reported two cases with perforation of the left colon among a series of 250 percutaneous nephrolithotomies (PCNLs) [6]. These two cases were both men with mobile kidneys.

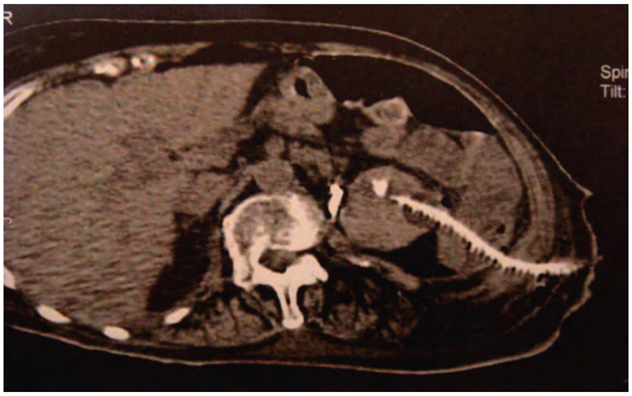

Figure 32.1 Nephrostomy tube transverses the left colon (retrorenal colon). Colonic injury during supine percutaneous nephrolithotomy (courtesy of Pr Bertrand Dore).

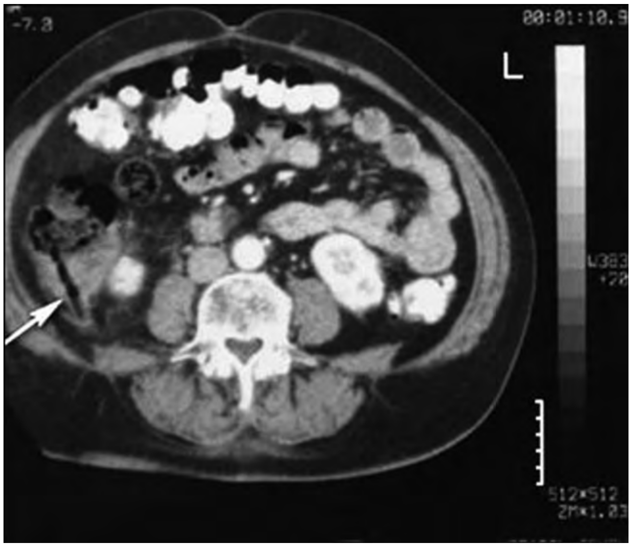

Figure 32.3 Nephrostomy tube is seen (arrow) in the right colon after colonic injury during a right percutaneous procedure.

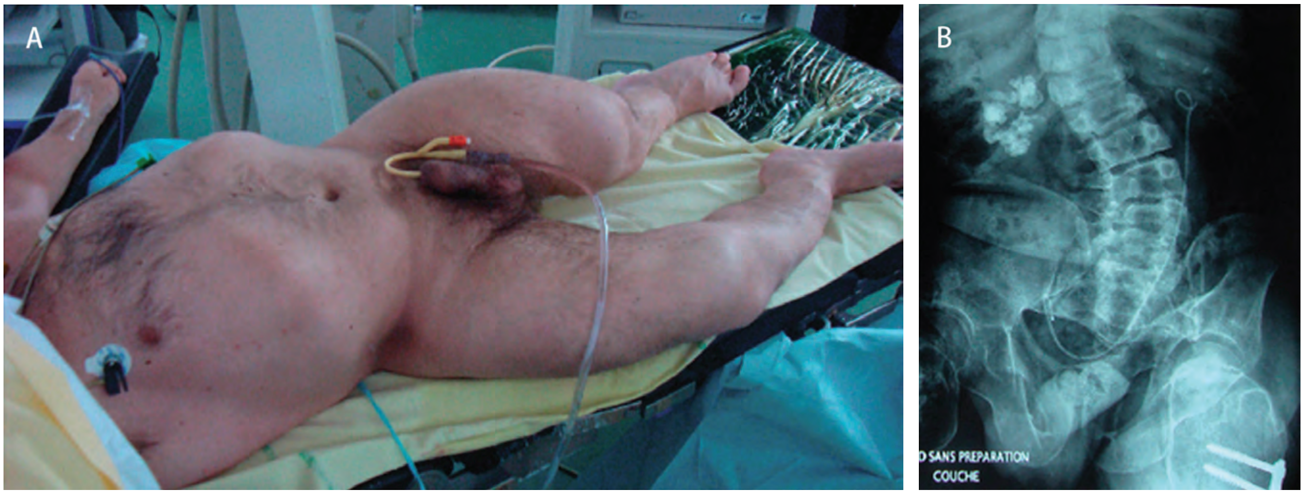

Figure 32.2 Patient with kyphoscoliosis and body deformities has high risk of colonic injury during nephrolithotomy.

The clinical signs were rectal hemorrhage with shock in one case and passage of gas through the nephrostomy tract in the other. The perforation was not suspected during PCNL, and both patients were treated surgically. The authors recommended open surgical repair when the perforation is intraperitoneal or there is a risk of complications, and simple surveillance when the perforation is extraperitoneal and there is no risk of complications.

Gerspach *et al*. reported on five patients with colonic injuries during percutaneous renal surgery (three on the left, two on the right) [25]. All had undergone PCNL, and all injuries were extraperitoneal. Three patients were considered lean, and the other two were of average body habitus. Recognition of colon injury occurred postoperatively in four patients and intraoperatively in one patient. Presenting signs and symptoms included fever, fecaluria, abdominal pain, and leukocytosis. The authors concluded that retroperitoneal colon injuries can be successfully managed conservatively with early recognition and appropriate drainage of the urinary and intestinal tracts. They also recommended, for high-risk patients, a more superior and medial puncture. More recently, El-Nahas *et al*. retrospectively reviewed 5039 PCNLs (1985–2004) and reported 15 (0.3%) colonic perforations [14]. The authors evaluated operative details and postoperative course to determine the time and mode of diagnosis of colonic injury, and treatment strategies and outcome. All injuries were retroperitoneal. Of the 15 patients (11 men, four women), the left side was affected in 10 (66.6%). The right side was injured only in those with horseshoe kidneys or with recurrent disease. Colonic perforation complicated lower calyceal puncture in 12 procedures (80%) and complicated upper calyceal punctures in those with horseshoe kidneys or chronic colonic distention. Significant independent risk factors for colonic perforation during PCNL were advanced patient age and the presence of a horseshoe kidney. The diagnosis was established intraoperatively in five patients and postoperatively in 10, five of whom presented with enterocutaneous fistula. The diagnosis was confirmed with abdominal CT or opacification of the colon during antegrade or retrograde pyelography. Conservative treatment was successful in all but two patients in whom a colostomy was necessary. El-Nahas *et al*. confirmed the conclusion of Gerspach *et al*. that early diagnosis and proper treatment represent the key to minimizing patient morbidity and avoiding serious complications, as have other authors, who have also recommended open surgical management in patients with transperitoneal perforation, peritonitis, or sepsis [3–6, 13].

In 1998, Wolf reported the principles of management of bowel injury during percutaneous stone extraction [18]. These principles include inspection of the PCNL tract for colonic injury whenever the tract is inspected for bleeding; a high index of suspicion for colonic injury when unexplained signs or symptoms of inflammation or infection develop postoperatively; and adequate drainage of both the colon and urinary collecting system.

Small intestine injury

The second and third portions of the duodenum may be injured during percutaneous renal surgery because they are adjacent to the right kidney, but this represents a very rare complication of PCNL and is rarer than colonic perforation. This can occur when the renal pelvis is perforated during dilation, or during placement of the working sheath or stone removal. This complication can be avoided with careful fluoroscopic monitoring during access, tract dilation, working sheath placement, and proper endoscopic manipulations. In 1985, Culkin *et al*. reported one case of a nephroduodenal fistula complicating PCNL that was managed conservatively [26]. The patient was discharged from hospital 14 days postoperatively, free of stone and doing well. The duodenum, positioned anteromedially to the right kidney, can be injured during right-sided percutaneous procedures if a needle or an instrument is advanced too deeply. In addition, it can be perforated if the back, stiff part of a guidewire is erroneously used for dilation of the nephrostomy tract.

Injury should be suspected if intestinal mucosa or contents are visualized or if communication with the small bowel is demonstrated on a nephrostogram or on the formation of a nephroduodenal fistula, which is also seen when postoperative nephrostography is obtained. In the face of a large perforation or patient instability, open surgical repair is necessary. For patients with small injuries of the small bowel and no signs of peritonitis or sepsis; however, nonoperative management may be attempted. For this group, antibiotics are administered and bowel rest is achieved with nasogastric suction and parenteral hyperalimentation. The nephrostomy tube should be positioned correctly to assure adequate drainage. Nephrostography and upper gastrointestinal radiography are performed 10–15 days after injury to assess for closure of the fistula [18, 26, 27].

Injury to adjacent structures

Pleura and lung (see also Chapter 31)

Pleura and lung complications are rare and most occur when the supracostal approach is used. Chest complications are the main morbidity associated with supracostal puncture during PCNL(0–12.5%). The majority of hydrothoraces are asymptomatic, and intervention is necessary in only a small percentage (4%) of patients [28]. Lojanapiwat *et al*. performed a comparison of the supracostal and infracostal approaches [29], reporting rates of pulmonary complications of 15.3% and 1.4%, respectively. When the supracostal approach is used, complications may be reduced by positioning an Amplatz sheath well into the collecting system and placing a well-draining nephrostomy tube to minimize the leakage of urine into the pleural. Chest fluoroscopy is recommended intraoperatively; however, routine chest X-ray is not mandatory if fluoroscopy is normal in the absence of respiratory signs [30]. A chest tube is necessary if there is a large pneumothorax or hydrothorax with or without signs of respiratory compromise. Renopleural fistula has been and is usually resolved with the placement of a thoracostomy tube; nevertheless, persistence of thoracic fluid should alert the urologist to perform intrarenal stenting. Lallas *et al*. reported rates of nephropleural fistula after supracostal PCNL of 2.3% (two of 87 cases) and 6.3% (two of 32 cases) during supra-12th rib and supra-11th rib access, respectively [31]. The incidence of nephropleural fistula increased to 3.3% when supracostal access was performed. Proper attention to the technique and intraoperative and postoperative monitoring can detect chest complications, and these can easily be managed with either aspiration or intercostal drainage without serious morbidity or death.

Liver and spleen

Due to the close anatomic relationship of the kidney and spleen on the left side, and the liver on the right side, iatrogenic injuries are associated with renal surgery and percutaneous access; however, hepatic and splenic injuries during PCNL are uncommon. The early diagnosis and treatment of splenic injuries can prevent associated morbidity and mortality, as missed splenic injuries are potentially fatal. A heightened suspicion for vascular injuries or splenic trauma in the perioperative period should be considered in patients undergoing PCNL with excessive blood loss, hemodynamic instability, or severe abdominal pain. A careful review of preoperative imaging can identify anatomic variants, such as splenomegaly or a retrorenal colon or spleen [32]. The factors that may predispose the spleen to injury during percutaneous renal procedures include splenomegaly, an intercostal approach, site of access (a more lateral placement poses a greater risk), and retrorenal spleen [32]. The nonoperative management of splenic injuries was associated with a high mortality rate. However, advances in imaging and new grading systems of splenic injuries have allowed select patients to be successfully managed conservatively, thus avoiding laparotomy and splenectomy [33]. Splenic artery angioembolization may allow the nonoperative management of splenic bleeding in select cases [34]. Repeat CT imaging can be performed to detect early signs of active bleeding; however, emergent splenectomy is warranted if conservative management fails or for patients with evidence of hemodynamic instability.

Liver injury during PCNL is very rare. Hopper and Yakes performed CT at both maximal inspiration and expiration with sagittal reconstructions in 43 randomly selected patients [35]. They found that the liver and spleen were not in contact with the supra-12th tract, but if the supracostal puncture was performed above the 11th rib during full expiration, the liver was punctured in 14% of cases. Hepatomegaly is another risk factor, even if the tract is made through the 11th intercostal space; therefore, such patients should be evaluated with a preoperative CT scan. Management of hepatic trauma is usually conservative, and surgical exploration is rarely needed (only in hemodynamically unstable patients). The nephrostomy tube should be left in place for almost a week to allow for tract formation. Sealing the tract with fibrin through the liver parenchyma during withdrawal of the nephrostomy tube has been reported [36]. Removing the nephrostomy tube and inserting a double-J stent at the same time is recommended to avoid a renobiliary fistula.

Conclusions

Bowel and adjacent organ injury may occur during percutaneous surgery. Patients need to be informed about this specific risk. It represents an unusual complication that is often diagnosed by postoperative nephrostography or patient clinical signs. The retroperitoneal colon is usually encountered anteriorly or anterolaterally to the lateral renal border. Therefore, the risk of colon injury is usually low. Colonic perforation may occur when the puncture site is placed lateral to the proposed posterior axillary line or in the rare event of a patient with a retrorenal colon. Typically, the injury is retroperitoneal; thus, signs and symptoms of peritonitis are infrequent. The majority of patients with colonic injuries can be treated without open surgical intervention with conservative measures, including adequate urinary and colon drainage, total parenteral nutrition (TPN), and antibiotic coverage.

Splenic injury can cause recalcitrant problems, including hemorrhage, and may eventually mandate splenectomy. A high index of suspicion is necessary for early diagnosis in view of the variability in clinical presentation. Splenic preservation should be attempted whenever possible to avoid the long-term risks created by splenectomy. Liver injury resulting from PCNL can be managed conservatively provided diagnostic, monitoring, and operating room facilities are available.

Proper patient selection and preparation, meticulous operative technique, and close postoperative care help to prevent the occurrence and decrease the magnitude of these complications. Prompt diagnosis of the complication and appropriate measures to rectify the problem will also limit its impact.

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SECTION 3
Ureteroscopy

CHAPTER 33

Ureteral Anatomy

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The normal ureter

The ureter refers to the hollow viscus that conveys the urine formed in the kidney to the urinary bladder. In the normal adult, the ureter is 25–30-cm (10–12 inches) long with a 4–5-mm caliber [1]. As it comprises the natural continuation of the renal pelvis, its beginning is defined at the ureteropelvic junction (UPJ), which lies posterior to the renal artery and vein [2].

The ureter runs caudal and medial in front of the psoas muscle, enters the bony pelvis, and terminates within the urinary bladder wall at the ureterovesical junction (UVJ). Its opening into the urinary bladder can be visualized endoscopically at the ureteral orifice.

For purpose of accurate location of various pathology along the course of the ureter and for further discussion or planning of certain interventional procedures, the ureter is arbitrarily divided into three segments [2]:

- Proximal ureter: relates to the ureteral segment that lies between the UPJ and the pelvic brim;
- Mid ureter: relates to the ureteral segment that is reflected over the sacral bone;
- Distal ureter: relates to the segment that lies between the lower border of the sacrum and the ureteral orifice.

An alternative nomenclature divides the ureter into the abdominal ureter, i.e. the segment that runs along the psoas muscle to the level of the iliac vessels (“*pars abdominalis*”), and the pelvic ureter, i.e. the segment that runs within the pelvic cavity from the level of the iliac vessels down to the urinary bladder (“*pars pelvina*”) [1]. Some refer to these two segments as the proximal and the distal ureter, respectively.

Histology

From inside out, the ureteral wall consists of urothelial mucosa, lamina propria, muscular layer, and an adventitial layer. The last two layers are separated by a potential space, named Waldeyer [3]. The mucosal layer consists of transitional epithelial cells in close contact. The lamina propria contains collagen fibers and fibrocytes, as well as numerous blood vessels and unmyelinated nerves. The muscular layer consists of muscle bundles, with each bundle consisting of 50–100 cells. The bundles are separated by collagen fibers. Some muscle cells extend beyond one bundle to communicate with another, therefore maintaining the continuity of the muscular layer [3].

Traditionally, the muscular layer was described as consisting of three layers: an inner and an outer longitudinal layer separated by a circular layer of muscle fibers [1]. Yet, it appears that this configuration does not exist in the human ureter [3]. Instead, the arrangement of muscle fibers varies among different sites in the ureter, and overall the muscle bundles have a mesh-like appearance. In the abdominal ureter, the muscle bundles form helices and no layers have been identified under light microscopy. Within the pelvic ureter, the muscle helices show some degree of layering with an inner longitudinal and an outer circular orientation. In the

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juxtavesical ureter, the inner longitudinal layer appears more prominent. The intravesical segment contains mainly longitudinal fibers, and the fibers of the roof shift laterally to join the bladder floor to build the trigone [3].

The adventitial layer of the ureter consists of bundles of collagen fibers, fibrocytes, nerve bundles, and muscle cells.

Blood supply and lymphatic drainage

The blood supply to the ureter originates from multiple arterial branches. The abdominal ureter is supplied by the abdominal aorta, renal artery, common iliac artery, and gonadal artery. The pelvic ureter receivess an additional supply from the internal iliac artery and its tributaries (i.e. vesical and uterine artery), as well as the mid rectal and vaginal arteries [2].

Of clinical importance to the urologist is the orientation in which blood vessels reach the ureter. The vascular supply to the abdominal ureter approaches anteriorly and medially, while the vessels supplying the pelvic ureter approach it posteriorly and laterally (Figure 33.1). Hence, laser incision of proximal ureteric strictures should be carried out in a lateral orientation, while laser incision of distal ureteric stricture should be performed medially.

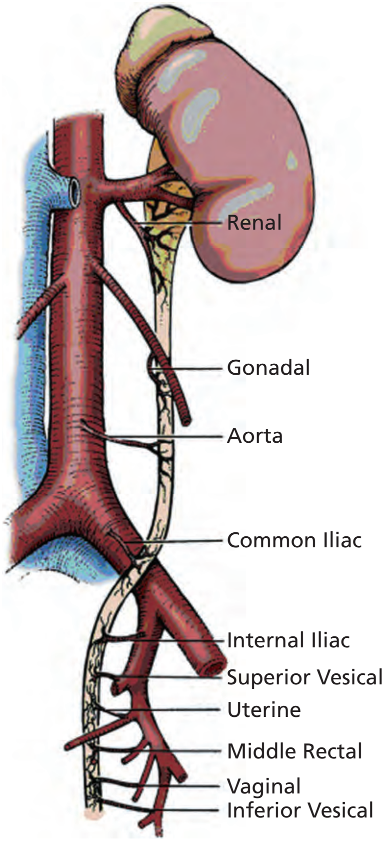

Figure 33.1 Ureteral blood supply (reproduced from Anderson *et al.* [2], copyright 2007, with permission from Elsevier).

Once the supplying vessels traverse the adventitial layer, they form an extensive arterial plexus along the ureter. This in turn protects the ureter when further mobilized for reconstruction purposes [2].

Lymphatic drainage of the ureter parallels its arterial supply. Lymphatic vessels originating in the pelvic ureter drain into the internal, external, and common iliac nodes. The left abdominal ureter is drained by the left para-aortic nodes, while the right abdominal ureter is drained by the right paracaval and inter-aortocaval lymph nodes [2].

Innervation

The lamina propria, muscular layer, and adventitia contain unmyelinated nerve fibers of adrenergic and cholinergic origins [3]. There is a controversy in the literature with regard to the presence of ganglionic cells in the ureter, as some investigators have demonstrated their presence in the pelvic ureter with associated dual adrenergic and cholinergic activity [4, 5], while others have failed to demonstrate this finding [3, 6, 7]. Consequently, ureteral neural activity was attributed to either action potentials originating within the ganglionic cells or to the myogenic nature of ureteral motility in which a stimulus is provided by a chemical mediator acting at a distance on the muscle cells or by the presence of a ureteral pacemaker [3]. Nevertheless, the neural activity continues following ureteral transection seen after ureteral surgery or after penetrating trauma.

Variants of the normal ureter

Ureteral medial deviation

Either bilateral or unilateral medial deviation of the ureter has been recognized as a normal variant of the ureteral course that can mimic medial deviation seen in retroperitoneal fibrosis. The incidence of medial deviation has been reported to vary between 15% and 18% [8], and is seen most commonly in young African–American patients [9]. Medial deviation appears to affect the right ureter more frequently than the left [8]. A possible explanation for this phenomenon is either pressure from adjacent vascular structures or psoas muscle hypertrophy [9].

Medial deviation of the ureter has been shown to occur most frequently at the level of L5–S1. At this level, the incidence of medial deviation was found to be as high as 11.2% in patients of Northern European descent versus 72% in patients of African descent with male predominance in both groups [8].

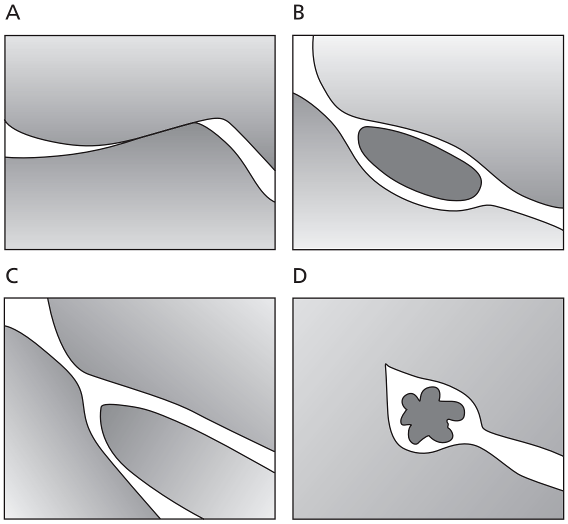

Figure 33.2 Ureteral orifice structures: A – normal cone ("grade 0"); B – stadium orifice ("grade 1"); C – horseshoe orifice ("grade 2"); D – golf hole orifice ("grade 3").

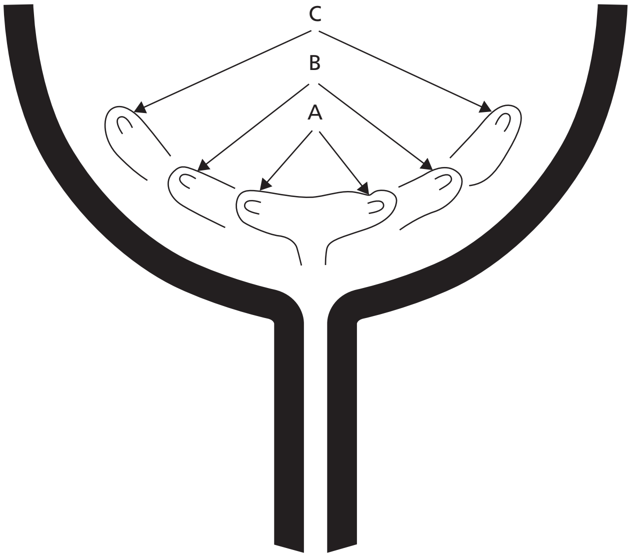

Figure 33.3 Ureteral orifice positions: A – normal position; B – lateral displacement; C – extreme lateral displacement (reprinted from Lyon *et al.* [10], copyright 1969, with permission from Elsevier).

As opposed to the medial deviation seen in retroperitoneal fibrosis, there is no associated dilation of the associated upper collecting system in these patients.

Ureteral orifice: structure and position

The ureteral orifice of a single collecting system falls into one of four structural categories: cone orifice ("grade 0"), stadium orifice ("grade 1"), horseshoe orifice ("grade 2"), and golf hole orifice ("grade 3") (Figure 33.2) [10]. Moreover, there are three different positions where the ureteral orifice can be located within the urinary bladder: A, the normal position in the medial aspect of the trigone where the orifice is held firmly by a strong trigone; B, a moderate degree of lateral displacement; C, extreme lateral displacement (Figure 33.3) [10].

In a study of 671 orifices, 54% were of grade 0 type (cone shape), 23% were of grade 1 (stadium shape), 15% were of grade 2 (horseshoe shaped), and 8% were of grade 3 (golf hole). Vesicoureteral reflux (VUR) was noted to occur most frequently in grade 3 and C positioned orifices [10].

Physiologic narrowing of the normal ureter

There are three points along the ureter where physiologic narrowing is expected: at the level of the UPJ, at the crossing of the iliac vessels, and at the UVJ. These points are of clinical significance for two reasons: first, these are the most common places for urinary calculi to be lodged while passing; second, they may limit the passage of either rigid or flexible endoscopes and therefore warrant special attention [2].

When placing a ureteroscope through the UVJ, the tip of the endoscope should be positioned parallel to the ureteral orifice's lateral wall, in order to avoid tears. Hence, the scope should be rotated in parallel with the bladder's posterior wall before entering the ureter. It must also be remembered that the anterior angulation of the ureter, where it passes over the iliac vessels, as well as the posteromedial angulation where the ureter enters the true pelvis and courses behind the bladder, may restrict the passage of a rigid ureteroscope [2]. Care must be taken to prevent undermining of the ureteral wall, as well as transaction or avulsion of the ureter. Therefore, consider using a flexible ureteroscope to access the mid ureter if a rigid endoscope cannot be easily advanced.

Ureteral anomalies: special considerations

Ureteropelvic junction stenosis/obstruction

The term UPJ stenosis refers to a relative narrowing at the area of the UPJ that may result in ipsilaeral hydronephrosis, flank pain, and compromised renal function. This abnormality originates from a combination of reduced muscle fibers and an excess of collagen tissue that results in inhibition or normal peristaltic motion across this segment, hence causing an intrinsic obstruction [11, 12].Other reasons for intrinsic obstruction may be either valve-like processes or polyps [12]. Incomplete prenatal recanalization at the UPJ has been proposed by others [13].

Extrinsic obstruction at the level of the UPJ can be found as well, and associated findings include bands, fixed angulations, kinks, high insertion of the ureter, as well as crossing vessels [12].

The narrowed UPJ may allow the passage of wires or ureteral catheters, but not urine [11]. Passage of a superstiff wire to straighten any kinks at the UPJ and decompress the distended renal pelvis may be warranted [14].

Endoluminal intraoperative ultrasonography with a 6.2F 12.5-MHz catheter-based transducer has been offered as a tool for detection of periureteral vessels adjacent to the UPJ or the septum of a high-inserting ureter [15]. In a study comparing various means of identifying crossing vessels in patients with UPJ obstruction, the incidence of crossing vessels was found to be highest when using spiral computed tomography (CT) (79%), followed by endoluminal ultrasound (58%). Open surgery and angiography were found to be relatively inferior to the former two methods, identifying only 46% and 33% of crossing vessels, respectively [12].

In an outstanding study performed by Sampaio and Favorito, the vascular relationship to the UPJ was analyzed in an attempt to determine the safest location to perform endopyelotomy [16]. A close relationship between a prominent vessel (either artery or vein) and the anterior surface of the UPJ was found in 65.1% of cases and in 6.2%, a close relationship between a prominent vessel and the posterior surface of the UPJ. In 20.5% of cases, a vessel crossed lower than 1.5 cm above the posterior surface of the UPJ, and in 73.3% the posterior surface was free of vessels up to 1.5 cm above the UPJ. Given these findings, the authors recommended avoiding a posterolateral incision at the UPJ, as the safest location for endoscopic incision appears to be the lateral ureter. If the insertion of the ureter is high, the incision should be performed through the septum, between the ureter and renal pelvis [15].

Ureteroscopy in children: the "delicate" ureter

Performing ureteroscopy in the pediatric population is challenging due to a relatively delicate ureter, small ureteral orifice, tight UVJ, and large psoas muscles [17, 18]. The main concern in this population is that advancement of a working instrument may be unsuccessful or cause damage to the ureter [17]. It is therefore recommended that the smallest available instruments should be used, such as flexible 6.9F or 7.2F ureteroscopes with a 2F and 3.5F working channel, respectively, or a 6.9F or 9.4F semi-rigid ureteroscope with a 2F or 5.4F working channel, respectively [18]. Some also recommend balloon dilation of the UVJ [14] and others gradually dilating the ureter in order to avoid traumatic ureteroscopy [17, 19].

While the possibility of ureteral damage is real, most studies have suggested that ureteroscopic procedures in children are safe. A retrospective study analyzing ureteroscopy results in 71 children found that ureteral dilatation was necessary in only 30% of the cases and the preferred method was gradual dilatation using ureteral dilators, as they were believed to cause the least trauma to the intramural orifice [17]. This conclusion was supported by a later retrospective study analyzing the results of 31 ureteroscopies performed in children [19]; 10F calibration of the UVJ allowed easier ureteral access and limited the need for formal dilatation to only two cases.

Horseshoe kidney

This congenital anomaly results from an abnormal fusion of the metanephric blastema. As a consequence, there is a failure of ascent and rotation. The ureters of the fused kidneys are highly inserted and laterally positioned compared to the normal ureteral anatomy. In addition, they are draped over the renal isthmus, which results in an anterior deviation of their course, several centimeters below the UPJ [20].

Their tortuous course, especially when they traverse the isthmus, makes semi-rigid ureteroscopy for proximal ureteral or renal calculi remarkably difficult and potentially unsafe. Flexible ureteroscopes have been used quite successfully to manage proximal ureteral calculi or stones within horseshoe kidneys [21].

On the other hand, ureteroscopy for a mid or distal ureteral stone can be carried out safely and effectively and in a similar manner to that performed in case of a normal kidney [20].

Pelvic kidney

A pelvic kidney results from the failure of renal ascent and, similar to horseshoe kidneys, the associated ureter is highly inserted and malrotated [20].

The use of an access sheath may be necessary in order to "straighten" a tortuous ureter.

Given the pelvicalyceal anatomy, which places the renal pelvis anteriorly, flexible ureteroscopy may be indicated to access the proximal ureteral and renal collecting system [20].

Duplicated collecting system

A duplicated collecting system, either complete or incomplete, is the most common ureteral anomaly with an overall incidence of 0.8%.

In a completely duplicated system, the ureteral orifice related to the upper pole moiety opens into the urinary bladder in a more caudal and medial location compared to the normal one, while the ureteral orifice related to the lower pole system opens in a more cranial and lateral location (Weigert –Meyer rule) [22].

Ureteroscopy in a duplicated system does not differ from endoscopy of a normal system, yet some principles should be kept in mind:

- In case of complete duplication with two ureteral orifices or incomplete duplication with a single ureteral orifice, the correct ureter should be properly identified and intubated. Failure to do so is most common in cases of incomplete duplication, where the second ureter bifurcates within the intramural segment of the bladder [23].
- In case of incomplete duplication, retrograde injection of contrast should help identify the level of the bifurcation when direct visualization is difficult [23].
- In case of incomplete duplication with a single ureteral orifice, it may be necessary to dilate the orifice, and directly intubate the intramural ureter by direct vision after slowly withdrawing the ureteroscope to the appropriate level [23]. In the presence of UPJ obstruction in a partially duplicated system, individual anatomic variances should be expected, and a combination of antegrade and retrograde ureterography may be required for better demonstration of the entire system. Retrograde incision of an obstructed proximal ureter or UPJ may be feasible, though a combined antegrade/retrograde access may be required if retrograde ureteroscopy alone cannot be performed in the standard fashion [24].

Endoluminal ultrasound may be useful in these cases for the detection of crossing vessels or an internal communication between the two renal pelvices, and a holmium laser has been reported as a possible treatment option in this unique anatomic variant [25].

Ureterocele

This term refers to a cystic dilation of the distal ureter [22]. The incidence of this rare anomaly is 0.025–0.2%. The ureteral orifice entering the ureterocele may be stenosed to various degrees [23].

The orifice can be dilated once intubated, and ureteroscopy is then performed in the usual manner. Alternatively, a ureterocele may be entirely occupied by a large stone which may not allow the advancement of a guidewire up the ureter. In these cases it has been suggested to unroof the ureterocele with an electrocautery knife or holmium laser, along its inferior border, thus raising a flap of mucosa through which the stone is manipulated into the bladder and further fragmented. Following stone removal, ureteroscopic access is feasible as the ureter proximal to the ureterocele is often dilated to some degree.

Ureteral pseudodiverticula

This term refers to a 3–6 mm outpouching of the ureter [26, 27]. As its name indicates, ureteral pseudodiverticula (UPD) involves only the mucosa [27].It is detected incidentally during retrograde or excretory urography. To date, approximately 80 cases have been reported in the literature [26, 27].

This is an acquired ureteral anomaly caused by chronic urinary tract infection, and has been found to be highly associated with uroepithelial malignancy. One study found that UPD in patients with radiolucent filling defects or urinary tract stricture correlated with malignancy in up to 71% of cases. This anatomic variant appears to represent a clinical marker, antedating urothelial carcinoma by 2–10 years [27].

Ectopic ureter

This ureter does not terminate in the normal trigonal position but rather more caudally and medially, either in the bladder neck or the urethra [22]. This anatomic location makes uretereoscopic access challenging, given the unusual orientation of its orifice. Suggested manipulations to intubate an ectopic ureter are: (1) intravenous injection of methylene blue for exact localization of the ectopic orifice; and (2) in case of a stenotic or difficult-to-identify orifice, antegrade placement of a guidewire should allow appropriate localization of the ectopic ureteral orifice. Alternatively, the entire procedure could be performed in an antegrade fashion following the establishment of percutaneous access to the relevant collecting system [23].

The reconstructed ureter: special considerations

Urinary diversion

Ureterosigmoidostomy

Though uncommon today, ureterosigmoidostomy was considered in the past to be one of the first-line treatment options for bladder extrophy or following cystectomy, and remains the standard of care in places where appropriate stomal care is not available [28].

The main complications associated with this type of diversion that require an endoscopic intervention are urolithiasis or anastomotic strictures [28–31]. The ureters are typically implanted into a sigmoid pouch, but ureteral relationship to a major anatomic landmark is absent. Moreover, the typical case scenario in these cases is that the urologist who originally performed the diversion is not the same one who deals with the delayed complication [28].

Provided the ureteral orifice is identified within the sigmoid pouch, retrograde ureteroscopy is feasible in the standard manner [29], yet it is strongly recommended to percutaneously insert a guidewire to be advanced in an antegrade fashion across the anastomosis, and serve as a through-and-through access [30]. This maneuver further aids in overcoming "unusual angles" to better delineate the anatomy during retrograde ureteroscopic access [28, 30, 31].

Feces has been noted to reflux into the collecting system during ureteroscopy; however, as long as proper drainage is maintained, this event should not lead to infectious complications. In addition to a nephrostomy tube, the preferred method of drainage is with a single-J biliary stent, which has multiple large side holes along its distal part, hence optimizing the drainage of both urine and feces [28].

Neobladders

Unique challenges have been identified with this type of urinary diversion. Often a retrograde approach to the implanted ureteral orifice is fraught with difficulty. Nonuniformity of the orifice location combined with mucosal folds often make identification of the ureteral orifices time-consuming, if not impossible.

In a Kock pouch diversion, the use of a flexible ureteroscope is strongly recommended, as the excessive torque required for a rigid endoscope to reach through an afferent nipple has the potential to injure the sphincter [31].

With a right colon pouch diversion, the delicate continence mechanism may be compromised using a standard cystoscope to identify the ureteral orifice. It would therefore be advisable to use an 8.5F ureteroscope instead [31].

In many orthotopic neobladder techniques, either one or both ureters are implanted into an afferent limb of bowel that extends from the reservoir. In such cases, identification of both the limb and associated ureters is crucial [32].

Direct visualization of the ureteral orifice requires flexible cystoscopy as access usually requires a "retroflexion maneuver." The ureter usually enters the reservoir at an oblique angle; therefore, the application of an angled-tip wire and a torque device may be useful to intubate the ureteral orifice [32].

Again, the key point in all these cases is placement of an antegrade guidewire through the collecting system down into the reservoir; it serves as a safety wire and a landmark when performing retrograde ureteroscopy.

Ureteroneocystostomy

The most common indication for this procedure is VUR in the pediatric population [33]. Reports of ureteroscopy performed on a reimplanted ureter have started to emerge as this pediatric population has entered adulthood, with an increased incidence of urolithiasis.

Ureteroneocystostomy can be divided into two broad categories: (1) that with relative preservation of the ureteral anatomy, e.g. the Glenn–Anderson procedure; and (2) that which significantly alters the course of the ureter as well as the location of the ureteral orifice, e.g. the Cohen technique [33].The Glenn–Anderson procedure is associated with repositioning of the ureteral orifice caudally and medially toward the bladder neck while preserving the normal course of the ureter [34]. The Cohen technique is associated with relocating the ureteral orifice to the contralateral side of the trigone in a submucosal tunnel [35].

Ureteral advancement using the Glenn–Anderson technique allows successful retrograde ureteroscopy, as well as stone fragment expulsion following shock-wave lithotripsy (SWL) due to the preserved straight course of the reimplanted ureter [33]. On the other hand, retrograde ureteroscopy following Cohen reimplantation is often impossible given the narrow angle between the endoscope and the reimplanted ureter [33, 36–40]. Possible maneuvers to overcome this problem include antegrade ureteroscopy [33]; antegrade percutaneous placement of an internal ureteral stent followed by retrograde urethral ureteroscopy [36]; percutaneous, needle-guided, transvesical trocar placement in direct alignment with the reimplanted ureter followed by transvesical retrograde ureteroscopy [37, 38]; and application of a 5F cobra-head catheter with the advancement of either a straight or angled-tip glidewire [39, 40].

Renal transplantation

Ureteral reimplantation during renal transplant results in an ectopic and anterior ureteral orifice, making its identification difficult [20].Nevertheless, retrograde ureteroscopy of a transplanted ureter can be successful with technique modifications [41, 42]. Intravenous indigo carmine is useful to identify the orifice. In addition, a flexible cystoscope as well as angled catheters (Kumpe or cobra) and angled hydrophilic glidewires may be useful for negotiating both the acutely angled transplanted ureteral orifice, as well as the frequently tortuous and redundant transplanted ureter [20].

Summary and conclusions

Whether the ureter has a classical or an unusual appearance, one should be familiar with both the normal and potential abnormal anatomy, as a result of congenital anomalies or previous surgical procedures. The anatomy of the ureter should never be overlooked when considering any type of endoscopic manipulation. Appropriate preoperative evaluation and intraoperative endourologic techniques should ensure proper, smooth, and usually successful endoscopic procedures.

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CHAPTER 34

Rigid and Flexible Ureteroscopes: Technical Features

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Introduction

The natural progression from open surgery to everyday minimally invasive endourologic procedures is testament to the evolution and technologic advances that have brought about the modern day ureteroscope. From the humble beginnings where Young performed the first recorded ureteroscopy in 1912 using a 9.5F pediatric cystoscope [1], the past century has seen the progression and diversification of the endoscope into state-of-the-art ureteroscopes offering rigid, semi-rigid, flexible, and composite designs to perform upper tract diagnostic and therapeutic procedures. The introduction of fiberoptics paralleled by the progression of instrument technology has led to smaller, more maneuverable scopes with more acceptable ergonomic layouts. The latest generation of ureteroscopes now provides high-definition digital images of the ureter and intrarenal collecting system, allowing procedures to be carried out safely, with high success rates and minimal morbidity in adults and children.

To appreciate how ureteroscopes have evolved into their present day guise, this chapter begins with a summary of key technical developments, starting with the first acknowledgment of the endoscope, the effect of changes in instrumentation, and progressing through to the latest digital technology. A breakdown of key features of ureteroscopes is then given, discussing their similarities and differences before moving on to consider ureteroscopes currently available and potential future trends for their further development.

Rigid and semi-rigid ureteroscopes

Rigid ureteroscopes

Historical perspective

The history of the endoscope is well documented [2–4] and its consideration sets the scene for the progression to present day ureteroscopes (Table 34.1). The traditional components required to carry out a rigid endoscopic procedure are the telescope with working channels for irrigation and instrumentation, a light source, optics to convey the image, and a camera system to capture the image. The digital era is here and will eventually condemn the fiberoptic arrangement to the historical archives.

The forerunner of the endoscope can be traced back to 1806 with the construction of the light-guiding instrument or "Lichtleiter" by Phillip Bozzini for direct inspection of internal organs [5]. This scope was basic in design, consisting of a direct-vision hollow tube through which candlelight was transmitted by a mirror. The French surgeon Antoine Jean Desormeaux further developed the Lichtleiter, producing the "endoscope" in 1853 using a system of mirrors and lens, and a kerosene flame to provide light to examine the urethra and bladder (Figure 34.1). Gustave Trouvé further upgraded indirect illumination by candlelight to electrical illumination using glowing heated platinum wires at the tip of the instrument in 1873 [5]. The filaments were later

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Table 34.1 Landmark evolutionary steps in the development of the rigid endoscope.

Year	Pioneer	Rigid endoscope and technologic advances
1806	Phillip Bozzini	German doctor who introduced the ""Lichtleiter" or light guiding instrument
1853	Antoine Jean Desormeaux	French surgeon who first introduced the "endoscope". Often considered as the father of endoscopy
1873	Gustave Trouvé	French inventor who moved the light source from outside to the inner tip of the endoscope and developed the "polyscope"
1879	Maximilian Nitze and Joseph Leiter	German urologist along with Viennese electro-optician Joseph Leiter are credited with the invention of the modern cystoscope
1960s	Several contributors	Introduction of fiberoptic cable enabling transmission of light from an external source
1960s	Harold Hopkins	British physicist filed a patent for the "rod–lens" system that was later adopted by Karl Storz in 1965

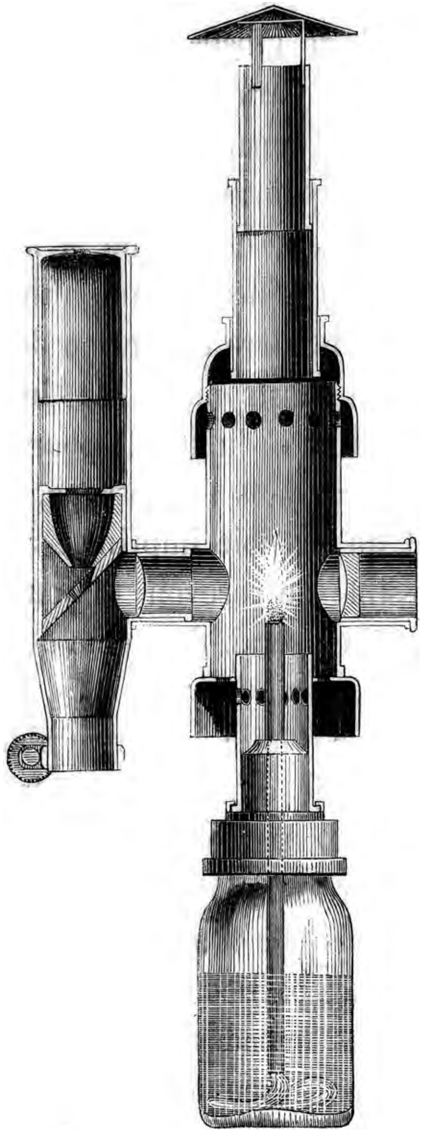

Figure 34.1 Antoine Jean Desormeaux modified the "Lichtleiter" to produce the 'endoscope'. From *De l'endoscope* by A.J. Desormeaux, 1865 (courtesy of Wellcome Library, London, UK).

replaced by Edison's incandescent light bulb. The Nitze-Leiter cystoscope, a rudimentary version of the modern cystoscope, was constructed in 1879, incorporating a simple lens system into the viewing tube [5].

The introduction of fiberoptic lighting in the 1960s replaced the incandescent bulb, revolutionizing the manufacture of rigid endoscopes. The design was based on the principle of total internal reflection; when light travels in a transparent medium such as glass, internal reflection of the light occurs at the interface between the medium and its surroundings, as demonstrated by John Tyndall in 1854 [6]. This physical property of internal reflection allows the "bending" of light within flexible glass. Thus, light travelling inside a small-diameter flexible glass fiber surrounded by cladding of lower refractory index can be transmitted over a long distance with minimal degradation. The benefit of modern fiberoptic lighting is greater illumination by cooler light, ultimately making it safer. An additional benefit is that the scopes can be made with a smaller-profile shaft, allowing more room within the shaft for the addition of an irrigation and instrument channel. The fiberoptic cable is often attached via a light post to the endoscope, but may alternatively be built into the design of the scope.

The innovative work of the British physicist Harold Hopkins led to the next major breakthrough in rigid endoscopic design with the introduction of the rod–lens system in the 1960s [7]. Until then, the shaft of the scope consisted of a hollow tube with a series of thin relay lenses separated by long air spaces. The relay lenses had to remain in precise alignment and any displacement of the lens resulted in a significant loss of image transmission. There was also a significant loss of light transmission with this system. Hopkins replaced the thin relay lenses within the shaft of the endoscope with long, contoured glass rods acting as the transmission medium, whilst the thin pockets interspersed between the glass rods acted as lenses. With the telescope primarily being made of glass, which has a higher refractive index than air, light transmission could be increased ninefold over previous lens systems, with the additional benefit of reduced image distortion and a wider viewing angle. The outer diameter of the endoscope shaft could also be reduced, paving the way for the development of the rigid ureteroscope and the introduction of working channels. The old lens system was notorious for its lack of durability and the Hopkins rod–lens system produced a significant improvement in this area. There were a few apparent weaknesses in the rod–lens design: any deviation in the use of the cystoscope from being used in straight lines, as can occur with the application of torque to the shaft, could lead to misalignment of the rod–lens set up and the permanent disappearance of up to half the image. The problem manifests itself as a half-moon or crescent-shaped defect when viewing through the scope eyepiece. This design flaw would be seen to be disadvantageous in the passage of the endoscope through the natural undulations of the ureter. A further consideration for ureteroscopic design centers on the diameter of the lens that dictates the size, or degree of magnification, of the image; the reduced diameter of the ureteroscope would inadvertently have a smaller image than the larger cystoscope.

Endoscopic evolution

Considering that Young undertook the first recorded ureteroscopy in 1912, it was another 65 years before Goodman [8] and Lyon *et al*. [9] ventured into the ureter, performing distal ureteroscopy in both male and female patients (Table 34.2). Goodman reported using an 11F pediatric rod–lens cystoscope to inspect the distal ureter in three adults [8]. In one of these patients, a distal ureteral tumor was fulgurated, marking the first ureteroscopically treated tumor. Lyon *et al*. reported ureteroscopy in five adults using Jewett sounds for ureteral dilation before passing an 11F pediatric cystoscope [9]. Most of these early ureteroscopy patients were women. Lyon *et al*. reported in 1979 the use of specially designed ureteral dilators attached to the tip of a flexible probe. They were able to dilate the orifice to 16F, permitting insertion of a standard length 13F cystoscope for distal ureteroscopy in men. These early investigators demonstrated the ease and safety of rigid ureteroscopy for the distal ureter in both sexes.

The first rigid ureteroscope specifically designed for ureteric use was produced in 1979 by Richard Wolf Medical Instruments and was modeled on a pediatric cystoscope. Lyon *et al*. reported its clinical use [10]. This 13F instrument had a working length of 23 cm, and sheath sizes of 14.5 and 16F, and a 16F resectoscope sheath were also available. The 13F sheath was used only for inspection, but the larger sheaths allowed simultaneous passage of a ureteral catheter or basket for stone manipulation and removal. For the first time, ureteral calculi were visualized, engaged in a basket, and removed [10, 11]. A longer ureteroscope that could reach all the way to the renal pelvis was developed by Enriqué Pérez-Castro in collaboration with Karl Storz Endoscopy, and its use was reported in 1980 [12]. Its 39-cm length allowed inspection of the renal pelvis for the first time. Initially hampered by the rod–lens system and size of shaft, other endoscope manufacturers quickly followed suit.

Further uerteroscopic modification was not due to advances in scope technology, rather the introduction of and progression in instrumentation. The launch of ureteroscopic ultrasonic lithotripsy for the treatment of urolithiasis would lead to modifications in ureteroscopic configuration. Initially, the probes were hollow and 8F in diameter, requiring removal of the telescope and blind stone lithotripsy, before being replaced by smaller solid probes that could pass through the working channels. These smaller probes (1.5–2.0 mm) were too rigid to negotiate the angles of the instrument working ports, and this led to the development of the offset eyepiece

Table 34.2 Landmark evolutionary steps in the development of the rigid ureteroscope.

Year	Pioneer	Rigid ureteroscope technological advances
1977	TM Goodmanand Edward Lyon	Provided the first reported series of distal ureteroscopically performed cases
1979	Richard Wolf	Credited with the design and construction of the first rigid ureteroscope
1980	Enriqué Pérez-Castro	Developed the “long” ureteroscope in collaboration with Karl Storz Endoscopy
1980	ACMI	The Rigiflex was the first ureteroscope to adopt the use of fiberoptics to allow the “gooseneck” eyepiece
1989	Huffman	Produced the 8.5F “compact ureteroscope” with a 3.5F-working channel. The rod–lens was integrated into the ureteroscope

which allowed the direct passage of the probe through a straight working channel under direct vision. Rigid ureteroscopes were later designed with an interchangeable offset eyepiece and standard telescope, allowing easier passage of the scope. Due to difficulties and complications from inserting rigid rod–lens type ureteroscopes with diameters approaching 14.5–15F, it became apparent that smaller ureteroscopes were needed. With the availability of smaller working instruments, Huffman described a compact ureteroscope that was 8.5F in diameter and had a working channel of 3.5F [13]. The rod–lens telescope was integrated into the ureteroscope, which helped decrease the outer diameter while maintaining a good-sized working channel.

General properties

The rigid ureteroscope has not deviated significantly from the original pediatric cystoscope used to inspect the ureter. Any development has centered on the improvement in the light source, the introduction of the rod–lens optics system, the launch of a single working channel, and changes in the overall ureteroscope dimensions. That said, over the years the ureteroscope has become narrow enough to ensure easier ureteric access and long enough to venture into the renal pelvis, and has a working channel to allow instrumentation for intervention and diagnostic purposes.

Optics, angle, field of view, and eyepiece

The rod–lens systems has provided excellent optical quality over the years, but scopes incorporating this design tend to have larger diameters and are prone to damage following angulation of the ureteroscope. The "angle of view" in an endoscope can vary from 0º, providing a straight view of the structure in question, to 70º, which allows inspection of tissues at an oblique angle from the straight axis. These rod–lens ureteroscopes were either interchangeable (from 0 to 70º angle of view) or integrated within the ureteroscope itself. The 70º lens was primarily used to inspect the renal pelvis and calyces, although these lenses are now virtually obsolete with the development of flexible ureterorenoscopes. The few current rod–lens ureteroscopes have integrated telescopes because of their smaller size advantage, and the angle of view through the objective lens is fixed at 0–5º. The advantage of a slight angulation on the direct vision lens is easier and quicker visualization of working instruments being passed out of the tip, reducing the potential for inadvertent iatrogenic injury to normal urothelium. The "field of view" is often quoted for ureteroscopes and is the entire view seen by the eye when it is trained in any particular direction. For endoscopes, this can vary from 60º to 90º, depending on the type of instrument.

Initially, ureteroscopes had a standard eyepiece design, which sees the ocular lens drawn in a straight line through the shaft of the scope. When rigid ultrasound probes were first introduced for ureteroscopic lithotripsy, an offset ocular configuration was trialed that allowed for direct access to the instrumentation port, allowing easy entry and removal of rigid accessories without impairing the view of the scope. Most companies went on to introduce offset eyepieces that were either fixed or movable.

Dimensions and sheath tip

From the earliest days of ureteroscopic evolution, the diameter of the rigid scope has come down from 16F to 8.5F, whilst the length of the scope ranges from 25 to 54 cm, allowing the length of the ureter to be accessed along with the renal pelvis. Early ureteroscopes had beaked tips emulating early cystoscopes, and on introducing the scope into the ureteral orifice, advancement could result in ploughing of the ureteral epithelium. Most current tip designs are beveled to provide safer and easier advancement into the ureter (Figure 34.2).

Working channel

The single channel in most rigid ureteroscopes varied in size from 3.5 to 5F, a range dictated by the size of the largest of instrumentsavailable at the time. The working channel was triangular in cross-section and allowed irrigation to continue around the sides of any deployed instrument within. Ureteroresectoscopes incorporated manually working elements much like standard transurethral resectoscopes. Working elements included resecting loops, cold and hot knife blades, and fulguration electrodes.

Semi-rigid ureteroscopes

Endoscopic evolution

Offering a different solution to the interchangeable offset eyepiece, the Rigiflex ureteroscope by ACMI was introduced in 1985. The eyepiece could be straightened for introduction into the ureter and later offset to admit the ultrasonic lithotripter. The ACMI HTO-5 was unique in being the first ureteroscope to incorporate fiberoptic imaging technology to produce the flexible "gooseneck" eyepiece. Although the scope had a 12.7F diameter shaft and a 5F single working channel, comparable rod–lens ureteroscopes of the time with a 5F channel were 14.5–15F in size.

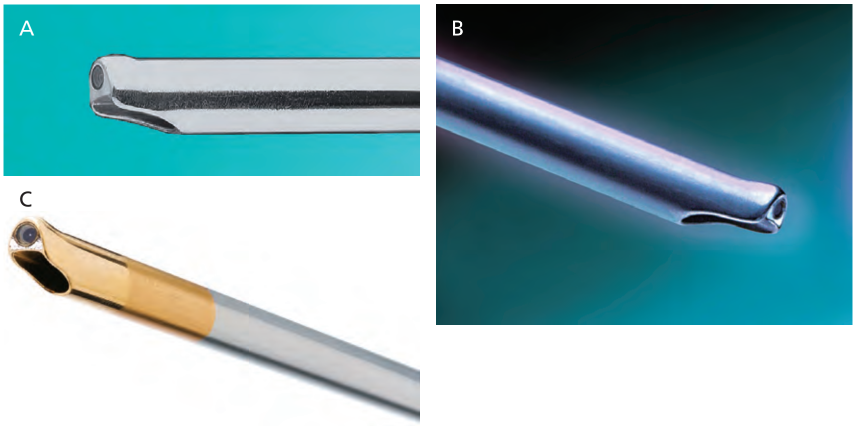

Figure 34.2 Ureteroscope atraumatic distal tip as seen on (A) Storz, (B) Wolf, and (C) Olympus scopes. The tips generally come beaked, beveled, or flat, as each manufacturer argues a case for easier atraumatic negotiation of the ureteric orifice (courtesy of Karl Storz, Richard Wolf, and Olympus Medical, respectively).

Ureterorenoscopy with a rigid scope still had inherent problems with the rod–lens optics due to the tortuous nature of the ureter and the caliber and working length of the instrument, which gave impaired vision. With the growing demand for rigid ureteroscopes in the 1980s, the further use of fiberoptic technology would enable further miniaturization of the shaft diameter along with reduction in size of the working channels. The "mini-scope" or semi-rigid ureteroscope combined smaller working channels and fiberoptics, allowing both illumination and image incorporated into a metal sheath. The optical system was reduced in size compared with the rod–lens design, leading to its primary advantage, an overall reduction in the outside diameter of the scope, but not at the expense of reducing the size of the working channels.

Although the rigid rod–lens system provided excellent optical quality, an additional advantage of the miniscope was that the fiberoptic bundles within the metal shaft could be flexed significantly without distortion of the image and the appearance of a dark crescent-shaped area that can occur with excessive torque applied to the rod–lens telescope. Such flexibility allows easier passage of the scope through the intramural ureter and then anteriorly over the iliac vessels with great maneuverability to negotiate narrowed or strictured ureters. Other advantages of the miniscope included easier access, reduced requirement for ureteric dilation, and decreased ureteric injury.

The first available "miniscope" was Candela Laser Corporation's semi-rigid ureteroscope, as described by Dretler and Cho in 1989 [14]. It was the first to incorporate two independent working channels, one for an accessory and one for flow, each of 2.1F size. It was the success of this 41-cm instrument with a 7.2F distal section that established it as the benchmark instrument of its time and prompted other US manufacturers to develop competitive instruments of similar design, such as the MR-6 ureteroscope from ACMI. The MR-6 proved to be much more durable than the Candela scope and quickly gained supremacy [15]. It had a sub-7F distal section with larger throughput capacity of one 2.3F and one 3.4F device in separate channels. The final distal shape was determined by enclosing the smallest size optical system the engineers could conceive at the time, along with the two separate throughput channels in a triangular-shaped outer tube, giving a 6.9F distal section. For the image system, by designing a conventional glass objective coupled to a 0.5-mm diameter fused quartz fiber bundle, more individual pixels of optical information were provided than the etched glass fiber bundle in either the Candela or the HTO-5 scopes. It came in a short 33-cm length version to allow access to the distal ureter and up to the ureteropelvic junction (UPJ) of females. The MR-6L was 41 cm long and was intended for use in males and obese patients. Over the past decade, miniureterosopes or semi-rigid ureteroscopes have been refined in terms of materials, ergonomic layout, fiberoptics, and camera systems, though there has been no really significant steps forward in scope evolution. They still remain the most commonly used type of ureteroscope [16].

General properties

Optics and eyepiece

In practice, the rod–lens ureteroscope, although offering quality images, allows only limited vertical deviation on advancement and is suited to ureteral sorties where the scope undergoes minimal change in direction. The introduction of fiberoptic bundles within a rigid shaft has enabled navigation through the more challenging tortuous ureter without leading to optical malfunction. Although earlier fiberoptic image bundles were disadvantaged by a characteristic graining effect, the pixel density in most current semi-rigid ureteroscopes has now increased beyond 30 000, such that the images are

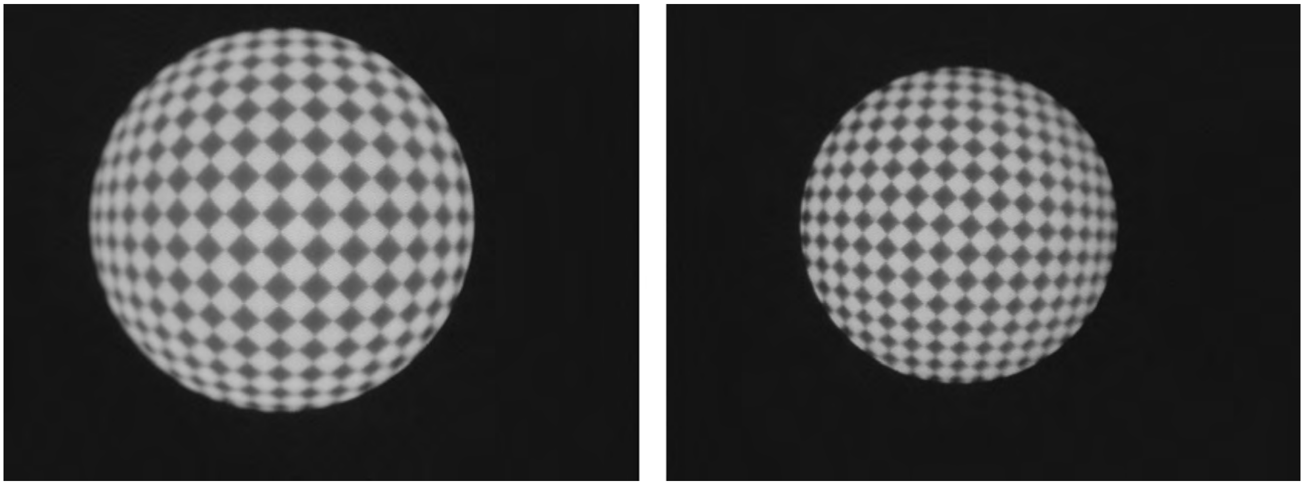

Figure 34.3 The latest improvements in bundle density mean the image size can be increased without compromising quality (courtesy of Richard Wolf).

large and bright and are much closer in quality and size to those of the traditional rod–lens system (Figure 34.3). Newer fiber-packing techniques and advanced camera systems have led to further improvement. Fiberoptic systems now provide light and image transmission through most current semi-rigid ureteroscopes.

As discussed earlier, offset eyepieces became necessary when rigid ultrasound probes were developed for ureteroscopic lithotripsy. These probes, as well as larger more rigid working instruments, required a straight working channel for passage through the scope. Offset eyepieces can either be fixed or moveable (Figure 34.4) and can be either angled or offset, although always straight and parallel to the ureteroscope shaft. The angle of view is usually 0–5°.

Dimensions and sheath tip

It is important for ureteroscopic design and procedural success that the scope is narrow and flexible enough to deal with the changing caliber of the ureter, with areas of natural lumen reduction at the UPJ, iliac vessels (12F), and vesicoureteric junction (3–10F), along with potential pathologic narrowing. Instrument manufacturers have made attempts to reduce the trauma of insertion by modifying shaft design and manufacture. The miniureteroscope shaft has a graduated stepless design, starting with a distal tip diameter as small as 6.9F [15], which rarely requires predilation of the ureteric orifice and intramural ureter, rising up to 13F in the larger scopes. This ensures maximal proximal strength of the scope whilst providing a gradual dilation of the ureter as the scope is advanced. The continued reduction in ureteroscope diameter has led to a reduction in the number of ureteral strictures seen and an increased success rate for the procedure [17]. Furthermore, the profile of the semi-rigid ureteroscope tip is designed to ensure minimal iatrogenic damage to the ureteric orifice and urothelium whilst maximizing the successful passage of the ureteroscope into the ureter (see Figure 34.2). Most of the currently available miniureteroscopes are beveled for easier advancement and have a round or oval tip design; however, scopes with smooth triangular tips have recently become available. The semi-rigid ureteroscope is generally manufactured in two lengths. A "short" ureteroscope of just over 30 cm can be used to access up to the level of the mid ureter in males and renal pelvis in females. To reach the renal pelvis in a male requires a "long" ureteroscope of 40 cm or more.

Working channel

Advances in construction of the miniscope led to the option of either a larger diameter single working channel with one large space for both irrigation and instrumentation to run through, or two separate working channels allowing separate instrumentation and irrigation (Figure 34.5). A larger single channel permits the use of larger instruments and possible removal of small stone fragments or biopsy specimens through the sheath, and dual instrumentation depending on the limits of each channel port. Two separate channels allow the operator to work through one channel without impeding irrigation flow through the other. The diameters of the two separate working channels range from 2.1 to 5.4F, but are usually 3.4F, allowing the introduction of a more rigid 3F instrument and 2.4F for irrigation or a second accessory. The channels are either triangular or oval in cross-section, which allows irrigation to continue around the sides despite the placement of an accessory instrument.

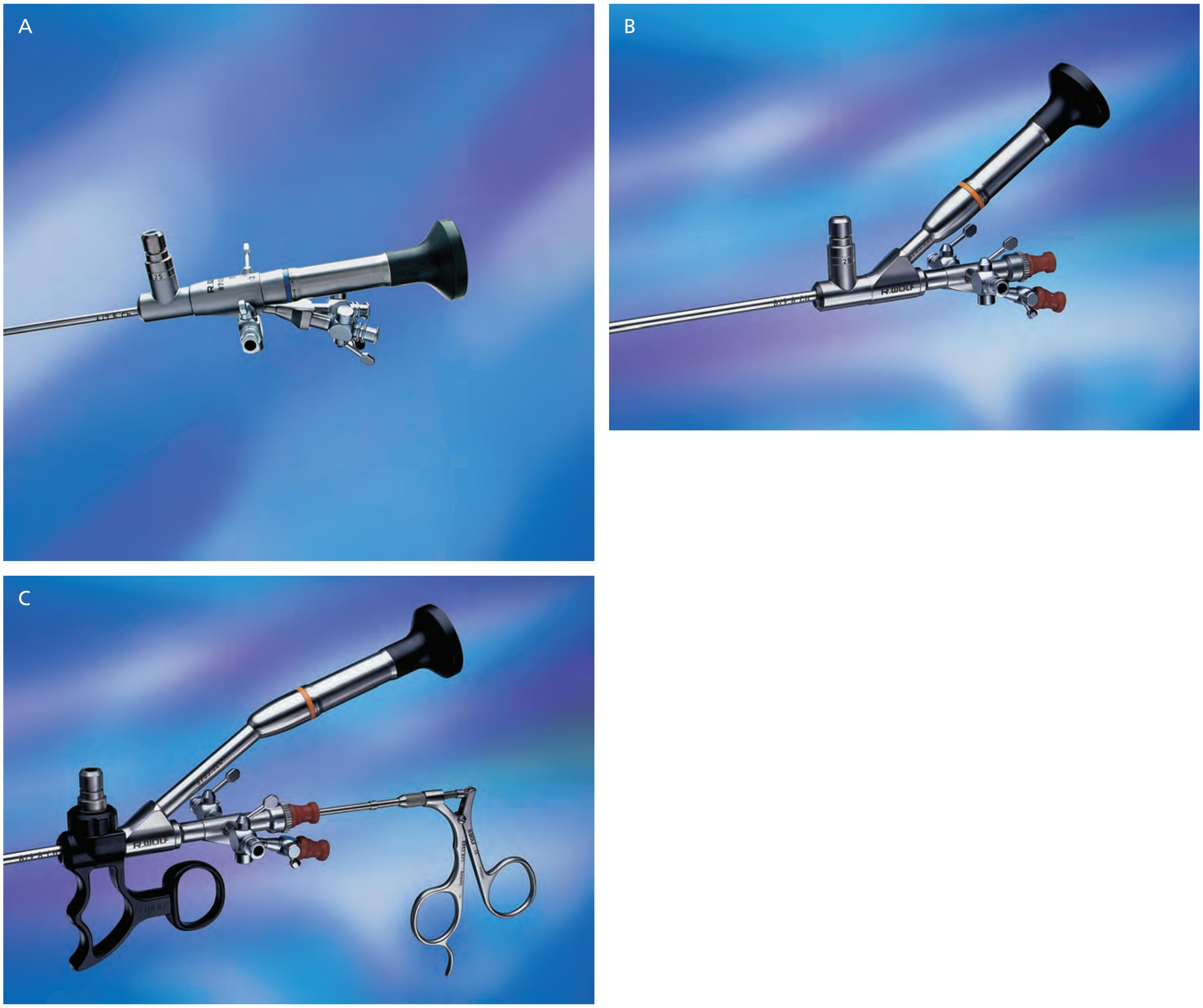

Figure 34.4 The Wolf E-Line series demonstrates the available eyepiece designs. These facilitate both easy insertion under direct vision with the (A) standard design, as well as the ability to use the straight rigid accessories in comfort with the (B) lateral and (C) oblique offset designs (courtesy of Richard Wolf).

The introduction of holmium laser lithotripsy for the treatment of upper urinary tract stone disease in 1996 [18] was a huge step forward in endoscopic stone treatment, and is now the bedrock of contact lithotripsy in most departments. With fiber diameter measuring only 200 and 365 μm, this has virtually abolished the requirement for anything larger than a 3.4F channel, allowing smaller outer diameter ureteroscopes to be used with better flow and therefore better vision. The narrow lasers also allow them to be used simultaneously with another accessory down a working channel, while still maintaining some flow.

Camera and video systems

Image transmission has evolved in line with changes seen with the semi-rigid ureteroscopes. Although images are occasionally viewed directly from the eyepiece due to technical problems or, rarely, the surgeon's preference, it has been conventional for some years to use indirect imaging on a television monitor using a video system. The video camera and monitor-based endoscopes allows binocular vision that is projected onto a large television monitor; this is ergonomically easier for the urologist and also can be enjoyed by the theater team. The high-resolution image output has also reduced the discrepancy between the better images obtained with the larger endoscopes compared with those previously seen with the ureteroscope.

Analog images produced by transmission down fiberoptic bundles continue to be the main pathway to deliver views of the subject matter to the camera in the majority of semi-rigid ureteroscopes. The drive to engineer semi-rigid ureteroscopes with digital distal sensor

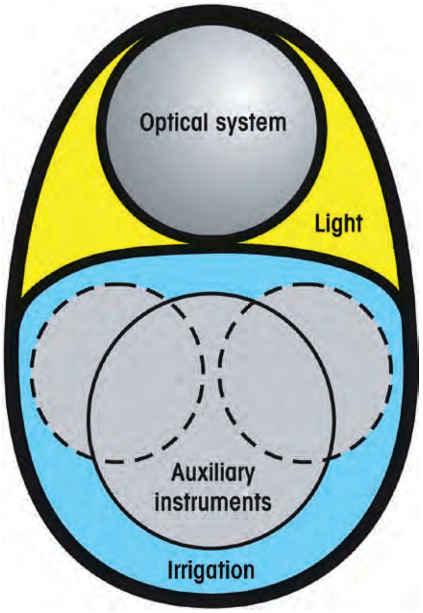

Figure 34.5 Possibilities available with single large- or twin-channel scopes with irrigation maintained (courtesy of Richard Wolf).

chip technology to produce high-quality digital images has not yet taken off to the same degree as seen with the flexible scopes. This is partly due to the high density of fiberoptic bundles that can be incorporated into the semi-rigid ureteroscope, which are more resistant to image degradation when compared to those found in the flexible ureterorenoscope. Olympus, however, produce the only digital semi-rigid ureteroscope, called the EndoEye video ureteroscope and also known as the Oes Pro Video, which has a distal charge coupled device (CCD) video chip (seeTable 34.3).

Irrigation

An effective irrigation system is important to optimize the chance of access into the ureteric orifice and provide good visibility during either rigid or flexible ureteroscopy. The simplest arrangement involves gravity irrigation, which has to contend with the small diameter and long length of the ureteroscope causing a reduction in flow. Other configurations are available that generate a greater pressure and therefore flow, with the pneumatic sleeve applied around the bag of fluid being the most common semi-automated set-up. Devices requiring operator/assistant input to supply increased flow on demand include attaching two 60 mL syringes via a Y-connector to inject irrigation as needed, and the Peditrol irrigation device that delivers a bolus via a foot pedal [19]. Automated infusion systems offering continuous saline irrigation, such as the Ureteromat, also exist which require no input from the endoscopist. The newly developed continuous-flow ureterorenoscope (10.5F) promises to provide a 100 times higher flow capacity whilst preserving the intrarenal pressure compared with conventional ureteroscopy *ex vivo* [20].

Current ureteroscopes

Rigid ureteroscopes are available in many of the designs previously described. The characteristics of the latest designs of currently available semi-rigid ureteroscopes are given in Table 34.3.

Care, maintenance, and technical failure

An important consideration when weighing up the purchase of a new ureteroscope is its longevity and often a balance is sought between optimal duration of scope life and its efficacy. Although less of a problem with the semi-rigid ureteroscope in comparison with its flexible counterpart, applying excessive torque causing deflections over 5 cm can lead to significant image distortion and scope failure. The majority of ureteroscopic failures are attributed to iatrogenic causes, including improper handling at the time of instrumentation and problems during the sterilizing process [21]. Regardless of the type and make of ureteroscope, the frequency of repair increases with decreasing ureteroscope diameter and increasing length of instrument [22]. Previously, with stepped shaft design of the rigid ureteroscope, bend stress was concentrated at solder points. Newer tapered shafts were produced to reduce this problem, making them more durable and less traumatic. Other notable risk factors for predicting the number of uses expected from a ureteroscope are its age and whether the ureteroscope has undergone comprehensive repair as a result of prior damage [21]. For optimal scope life, it is important that optimal care is taken in looking after the instrument and cleaning procedures are carried out with strict adherence to company instructions.

Flexible ureteroscopes

Flexible ureteroscope versus rigid ureteroscope?

Flexible ureterorenoscopy has developed rapidly over the past 30 years as technologic improvements have been made in both instrument size and design. Advances in fiberoptic technology, improved deflecting mechanisms, and a greater diversity of working instruments, have all increased the utility of the flexible ureterorenoscope in the diagnosis of upper tract disorders. This has led to ever-increasing indications for minimally invasive diagnostic and therapeutic interventions. Over the same time frame, the number of ureteric complications

Table 34.3 Specifications of currently available semi-rigid ureteroscopes.

Model	Eyepiece	Field of view (degrees)	Diameter (F)	Length (mm)	Sheath construction	Tip style	Angle of view (degrees)	Working channels	Channel size (F)
Olympus Gyrus – ACMI									
MR-6A Bagley	Straight	65 ± 5	6.9–10.2	330	Stepwise	Beveled	5	2	3.4 + 2.3
MR-6LA Bagley	Straight	65 ± 5	6.9–10.2	330, 410	Stepwise	Beveled	5	2	3.4 + 2.3
MRO-733A	Angled	61	7.7–10.8	330	Stepless	Beveled cutaway	5	1	5.4
MRO-742A	Angled	61	7.0–11.2	420	Stepless	Beveled cutaway	5	1	5.4
Olympus									
OES Pro Single	Straight	90	6.4–7.8	330, 430	Stepless	Beaked	7	1	4.2
	Angled	90	6.4–7.8	330, 430	Stepless	Beaked	7	1	4.2
	Angled	95	8.6–9.8	430	Stepless	Beaked	7	1	6.4
	Flexible	90	6.4–7.8	430	Stepless	Beaked	7	1	4.2
	Flexible	90	8.6–9.8	430	Stepless	Beaked	7	1	4.2
OES 4000 Double	Straight	90	7.5	430	Flat	None	7	2	3.4 + 2.4
	Angled	90	7.5	330, 430	Flat	None	7	2	3.4 + 2.4
OES Pro Video*	N/A	95	8.5–9.9	430	Stepless	Beaked	7	1	4.2
Karl Storz									
27001K/L	Angled	–	7.0–13.5	340, 430	Stepwise	Beaked	6	1	5.0
27002K/L	Angled	–	8.0–13.5	340, 430	Stepwise	Beaked	6	1	5.0
27003K/L	Angled	–	9.0–15.0	340, 430	Stepwise	Beaked	6	1	5.0
27010K/L	Straight	–	7.0–9.9	340, 430	Stepwise	Flat	6	1	3.4
27011K/L	Straight	–	7.0–13.5	340, 430	Stepwise	Beaked	6	1	5.0
27012K/L	Straight	–	8.0–13.5	340, 430	Stepwise	Beaked	6	1	6.0
27014K/L	Remote	–	9.0–15.0	340, 430	Stepwise	Beaked	6	1	5.0
Stryker									
SRU-6X	Standard	–	6.9–10	430, 330	Stepless	Flat	6	2	3.4 + 2.5
Richard Wolf									
8702 (.517, .518)	Straight	90	6.0–7.5	330, 430	Stepless	Beaked	5	1	4.0
8703 (.517, .518)	Straight	95	8.0–9.8	330, 430	Stepless	Beaked	12	1	5.0
8708 (.517, .518)	Straight	90	6.5–8.5	330, 430	Stepless	Beaked	5	2	4.2 and 2.55
8702 (.523, .524)	Oblique	90	6.0–7.5	315, 430	Stepless	Beaked	5	1	4.0
8703 (.523, .524)	Oblique	95	8.0–9.8	315, 430	Stepless	Beaked	12	1	5.0
8704 (.523, .524)	Oblique	95	8.5–11.5	315, 430	Stepless	Beaked	12	1	6.0
8701 (.533, .534)	Lateral	95	4.5–6.5	315, 430	Stepless	Beaked	5	1	3.0
8702 (.533, .534)	Lateral	90	6.0–7.5	315, 430	Stepless	Beaked	5	1	4.0
8703 (.533, .534)	Lateral	95	8.0–9.8	315, 430	Stepless	Beaked	12	1	5.0
8708 (.533, .534)	Lateral	90	6.5–8.5	315, 430	Stepless	Beaked	5	2	4.2 and 2.55

*Distal sensor digital ureteroscope.

associated with ureterorenoscopy has significantly decreased [23, 24]. Although differing significantly in cost and complexity, the flexible ureterorenoscope should not be considered as a separate entity from the semi-rigid ureteroscope. Both types of ureteroscope are in fact used in a complementary fashion to access, inspect, and treat pathology in the entire upper urinary tract collecting system [25]. So complementary, in fact, that it is common practice to first use the semi-rigid ureteroscope with its graduated increase in diameter to optically dilate the ureteral orifice and lower ureter, both to ease passage of the flexible scope and increase the longevity of the delicate smaller caliber flexible ureterorenoscope. The rigid ureteroscope is therefore ideal for managing pathology in the lower aspects of the urinary tract, whereas the flexible ureteroscope is better suited to the upper ureter, renal pelvis, and calyces. Using active tip deflection, the flexible ureterorenoscope is able to negotiate the angulations of the ureter and pass safely beyond the iliac vessels before being advanced all the way up to the intrarenal collecting system under direct visual control.

Flexible endoscope development

Fiberoptic endoscope

The existence of the flexible endoscope owes a great deal to the development of fiberoptic technology, the principles of which were developed over a century ago by John Tyndall (Table 34.4). Based on the physical properties of light [6], small-diameter transparent glass fibers when bundled randomly will uniformly transmit light from one end to the other (even when bent), but no image. The use of glass fibers in a "noncoherent" arrangement to provide illumination was soon followed by the introduction of fibers bundled together coherently and with identical orientation at either end. These dots of light coalesce to transmit images [26] to the eyepiece (Figure 34.6). The view seen is therefore made up of thousands of images from each individual fiber to produce a composite matrix image. In the 1950s, Harold Hopkins designed the "fiberscope," a coherent bundle of fibers with the ability to transmit images [27]. It was not however until 1957 that the South African physician Basil Hirschowiz created a diagnostic flexible endoscope that was fit for clinical practice. Using superior glass fiber technology, the potential of his invention was soon realized by several medical specialities, and flexible endoscopy was in widespread use by the mid-1960s.

Subsequent improvements in fiberoptic technology have allowed the bundling together of greater numbers of fibers, along with a second layer of glass cladding that has a different refractive index from the core of glass. This design is much more durable than the previous uncladded designs. The interface between these two different glasses produces the internal reflection [6, 28], resulting in the production of a sharper image with better illumination. The additional cladding does not, however, transmit light and causes a mesh-like or honeycomb appearance of the image, known as the Moiré effect. The advances in fiberoptics have not only produced superior images, but have also enabled a reduction in instrument size, allowing for both larger working channels and a smaller outer shaft diameter. Further modifications to the endoscope have allowed its tip to be actively manipulated by the endoscopist along with the development of instrument channels.

Digital endoscope

The image quality with the fiberoptic endoscope is limited by the finite diameter of the image-carrying glass fibers, leading to the pixelated "chicken wire"

Table 34.4 Landmark steps in the evolution of the flexible endoscope and ureteroscope.

Year	Pioneer	Flexible endoscope and ureteroscope technologic advances
1854	John Tyndall	Noted that when light travels in glass, internal reflection of the light occurs at the interface between that medium and its surroundings
1950s	Harold Hopkins	Designed a "fibroscope," a coherent bundle of flexible glass fibers able to transmit an image
1957	Basil Hirschowiz	Using a superior glass fiber for the flexible endoscope resulted in the first clinically practical endoscope
X1960	Marshall	Used a 9F flexible fiberscope to visualize the renal pelvis to inspect for calculi
X1962	McGovern and Walzak	Used a 9F passive, channel-less flexible fiberscope to visualize an impacted ureteric calculus
1971	Takagi *et al.*	First clinical use of an actively deflectable fiberoptic ureteroscope for the visualization of the urinary tract
X1970	Boyle and Smith	Created the charge coupled device (CCD) – a chip that can store data in the form of electric charges
1983	Bagley	Introduction of a passively deflectable flexible ureteroscope with combined irrigation and working channels
1994	Grasso	Reported the use of a new two-way deflecting 7.5 F flexible ureteroscope with active and passive deflection
2005	ACMI Digital Endoscope	First commercially available digital sensor endoscope brought into production with a lighter more ergonomic design
2006	ACMI Digital Ureterorenoscope	First commercially available digital sensor ureteoscope brought into production with a lighter more ergonomic design

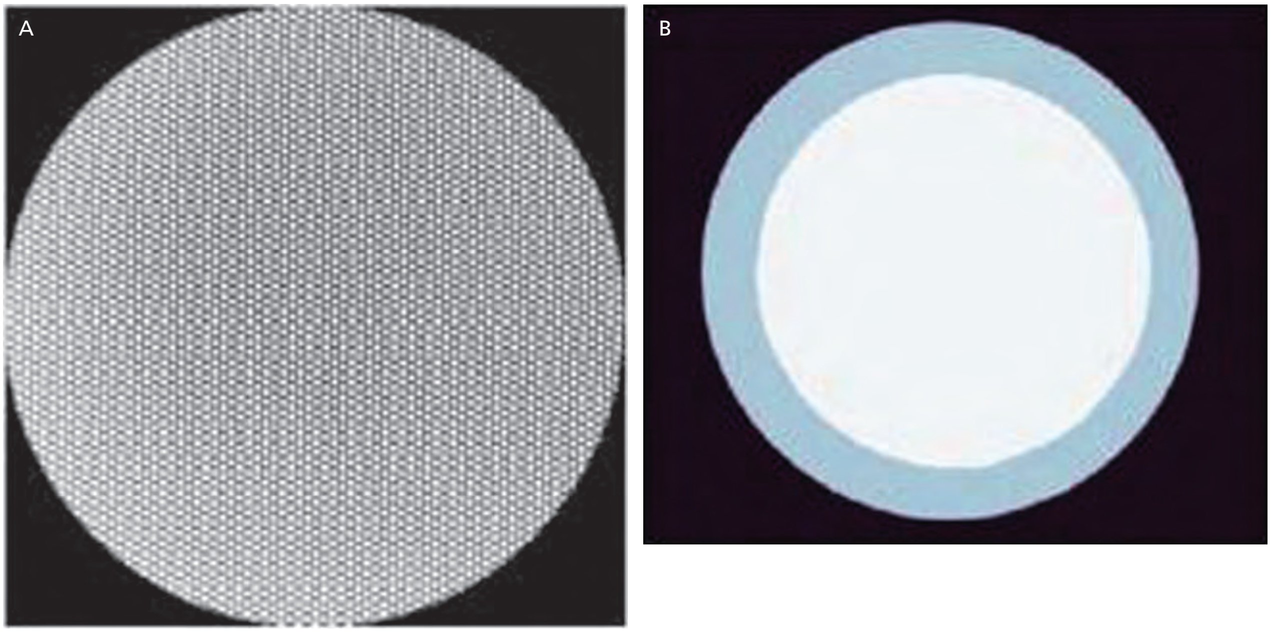

Figure 34.6 (A) Magnified view of composite images from a flexible fiberoptic imaging bundle and (B) magnified view of a single fiber with a central glass core and cladding of different optical refraction.

effect. Digital endoscopes are fundamentally different from their analog counterparts with no fiberoptic cable or viewing ocular lens. Instead, the image seen at the distal tip of the scope is electronically and digitally transferred through a single cable and recreated on a televisions monitor. The catalyst for their creation came from work in 1970 by Boyle and Smith who produced a microchip that could store electric charge (the CCD) for storage of data that could be retrieved at a later time [29]. A similar low-cost storage alternative was patented in 1967 and called the complementary metal oxide semiconductor (CMOS). Both CCD and CMOS devices are digital sensors composed of millions of photodiodes that convert photons into electric current that is transformed into a voltage, amplified, and converted to a digital form [30]. The image is digitally transferred via a single cable to a distant processor, which reconstructs and enhances the image electronically on a television monitor. These high-quality images, once captured, can be easily stored and transferred using a commercially available computer storage medium.

In 2005 the first commercially available distal sensor endoscope was the ACMI DCN-2010 digital cystoscope. With a digital camera and light emitting diode (LED) light carriers the net gain was better image quality and improved contrast, resolution, and color discrimination [31, 32]. Additional benefits included a lighter scope with less cabling and improved ergonomics. Such was the improvement with the digital sensor endoscope, lesions down to 1 mm in size could be clearly identified at a greater distance when compared with the fiberoptic scope. The introduction of the distal sensor endoscope represents an important historical landmark in the development of the endoscope.

Flexible ureterorenoscopes

Flexible fiberoptic ureterorenoscope

Given the complexity of engineering and construction of the flexible ureterorenoscope, it is surprising to find that its inception predated that of its semi-rigid counterpart by over a decade. In 1960 Marshall reported the first clinical use of a 9F fiberscope produced by ACMI to visualize an impacted ureteral stone during open surgery through a ureterotomy [33]. This ureterorenoscope was rudimentary in function with no active deflection. Marshall's colleagues, McGovern and Walzak, made the first transurethral flexible ureteroscopy 2 years later with the 9F fiberscope passed through a 26F McCarthy endoscope to a level of 10 cm in the ureter to diagnose a ureteral stone. In 1968, Takagi *et al*. similarly performed transurethral ureteroscopy using a small 8F passive, channel-less, fiberoptic endoscope of 70 cm in length to visualize the renal pelvis and calyces [34]. Manitol-induced forced diuresis was often required to make up for the lack of an irrigation channel. With increasing improvements in fiberoptic technology, Takagi *et al*. reported the first clinical use of an actively deflectable fiberoptic ureteroscope [35], which allowed some maneuverability of the tip of the scope. The fiberoptic ureteroscope was limited by the small deflection angle and lack of an irrigation channel, and was difficult to insert. The subsequent development of a cystoscopically placed guide tube into the ureter (the original access sheath) allowed irrigant flow around the perimeter of the instrument for better visualization of the ureteral mucosa and pathology [36], though the views obtained were still far from ideal. The supportive nature of this technique did offer some protection when passing the delicate flexible scope, a problem that had hampered previous flexible scopes, which tended to buckle without the additional support.

The next evolutionary step in flexible ureteroscope design came in the 1980s when the inclusion of an irrigant and working channel were combined and incorporated into the next generation of ureteroscopes at the University of Chicago by Bagley *et al*. [37, 38]. For therapeutic and diagnostic purposes, such channels were essential. At the same time, a further technical advance was the development of ureteroscopes that could actively be steered, leading to endourologists being able to treat upper urinary tract pathology. Takagi's group had previously noted when passing the endoscope through a catheter that additional torque could be applied, allowing them to persuade the tip to pass in the desired direction, and thus establishing the importance of developing a deflectable tip endoscope. In 1983 a newly designed 55- and 80-cm flexible tip ureteropyeloscope was trialed by Bagley *et al*. [37, 38]. The tip deflection, which was in the same plane, was bidirectional: 160° in one direction and 90° in the opposite direction. Removing the telescope of the rigid ureteroscope allowed the flexible ureteroscope to be passed through the rigid sheath. To determine the optimal amount of tip deflection necessary to examine the entire intrarenal collecting system, Bagley and Rittenburg measured the angle between the major axis of the ureter and the lower pole infundibulum (the ureteroinfundibular angle) from the radiographs of 30 patients [39]. The average angle was 140° with a maximum of 175°. Primary active deflection of 175° should allow ureteroscopic negotiation of this ureteroinfundibular angle in most patients.

Several flexible deflectable ureteroscopes became available in the late 1980s, varying in size from 8.1F to 10F and with working channels of differing diameters. Despite the reduction in size due to advances in optical technology, access to the lower pole calyceal system remained difficult. In 1991 Grasso *et al*. reported the use of a small diameter, actively deflectable flexible ureteroscope [40]. This new scope had a tapered design with an 8.2F proximal sheath and a 7.5F distal tip giving improved access to the ureteric orifice. The working channel was maintained at a respectable 3.6F, allowing the use of most instruments. The instrument was capable of active deflection of 170° (down) and 120° (up) with secondary passive deflection if required, both of which gave successful appraisal of the intrarenal collecting system, in particular the lower pole. The addition of passive deflection allows lengthening of the deflected segment and permits inspection and treatment of the entire intrarenal collecting system [41, 42]. Secondary passive deflection is made possible by the presence of a more flexible segment of the ureteroscope located just proximal to the point of active deflection (Figure 34.7A); this allows the angled tip of the ureteroscope to be bent off the superior margin of the renal pelvis, or the neck of a middle-pole calyx when a baggy extrarenal pelvis is present. This effectively extends the tip of the ureteroscope, allowing inspection of the lower pole calyces with greater ease. This portion of the collecting system can be visualized in over 90% of patients when passive deflection is possible [41]. The latest advances in active deflection incorporate secondary active deflection into a flexible ureterorenoscope design. The first such scope was the DUR-8 from ACMI. This unique arrangement allows the operator to deflect the scope tip upwards by 175° and downwards by 185° by fully activating the primary deflection lever on the handpiece, and then by activating a second lever on the opposite side of the handle, a further 135° downward deflection of the tip can be obtained, to give a total of 315° downward deflection. The primary purpose of such a design is to access the lower pole calyces, which are usually the hardest to reach (Figure 34.7B, C).

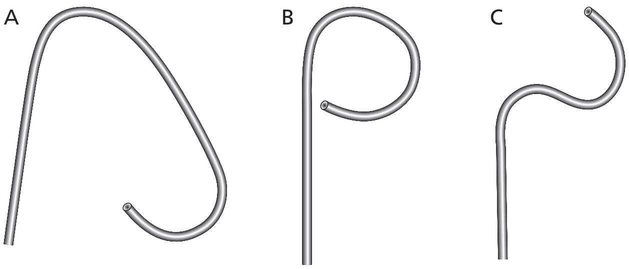

Figure 34.7 (A) Demonstration of a flexible ureterorenoscope's primary active deflection followed by a secondary passive deflection. (B, C) Dur-8 Elite flexible ureterorenoscope, the first instrument to incorporate secondary active deflection (courtesy of Olympus Medical).

Flexible digital ureterorenoscope

The impact of the arrival of the digital sensor ureterorenoscope should not be underestimated and the emergence of this new technology has great potential. Following on from the introduction of the ACMI DCN-2010 digital flexible cystoscope in 2005, the following year saw the launch of the ACMI DUR-D digital flexible ureteoscope (Figure 34.8; see Table 34.4). The scope utilizes the CMOS distal imaging sensor measuring 1 mm and built-in LEDs for illumination, negating the require-

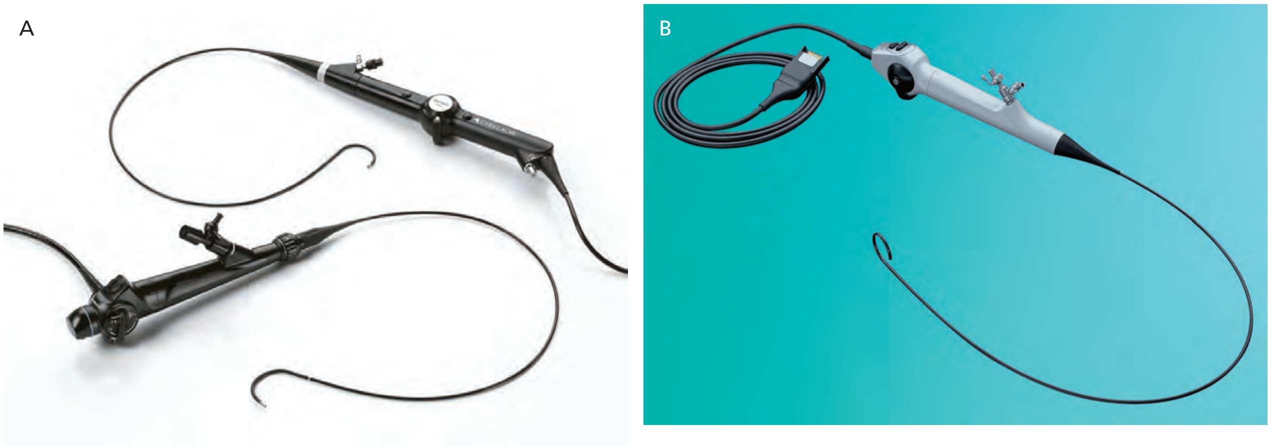

Figure 34.8 (A) Olympus DUR-D and ACMI DUR-D, and (B) Storz Flex-XC video ureterorenoscopes (courtesy of Olympus Medical and Karl Storz, respectively).

ment for a separate bulky light source. During its initial use, some concern was highlighted regarding the use of lasers down the working channel, which led to interference with the CMOS chip and a poor image. Through software upgrade and fine-tuning of the electronic circuitry, this problem appears to have been overcome. The shaft is constructed of nitinol for strength, lightness, and durability, and is tapered in design.

General properties

Flexible fiberoptic ureterorenoscope

Traditionally, all flexible endoscopes have involved similar basic components, including a fiberoptic bundle providing imaging and a light source, a working and irrigation channel, and a deflection mechanism. In addition, but of no less importance, are the camera, video system, and pressurized irrigation supply. Although the earlier generation of flexible fiberoptic ureteroscopes was limited by the lack of irrigation, active deflection, and instrumentation, with continuous refinement and improvement in all these areas the modern flexible ureterorenoscope now has a narrower shaft diameter with increased active tip deflection facilitating passage of scopes into the upper ureter and lower pole calyx [43]. The design of newer endoscopic instruments and energy sources has led to further advances in and miniaturization of endoscopic construction. The following sections discuss general details specific to the fiberoptic ureteroscope before moving on to state-of-the-art distal digital sensor ureteroscopes.

Conventional imaging

Along the full length of the shaft, each ureterorenoscope has one or two haphazardly arranged noncoherent bundles for light transmission, plus a single coherent fiberoptic bundle for image transmission. Using two sets of light transmission bundles gives consistent illumination and decreased shadowing. The fibers found in the bundle carrying the image are smaller and are aligned end-to-end in an identical arrangement so that the exact image is transmitted to the ocular lens at the eyepiece. The image obtained is not a single image but is formed by the addition of every individual fiber within the bundle to give a single reconstructed image (see Figure 34.6). Each optical fiber in the bundle is approximately 8 μm in diameter and is composed of glass possessing a higher refractive index than the surrounding cladding. This composition allows for excellent light and image preservation over long distances and around significant flexion of the bundle.

The angle of view from the tip of the instrument can be modified by changing the axis of the optical system at the tip [44]. This is usually accomplished with a wedge lens system at the distal end of the imaging bundle. This modified angle of view can be up to 10° in fluid and is helpful in visualizing working instruments as they emerge from the tip of the scope. This is particularly helpful when using the more translucent laser fibers, which, being made of quartz, can easily cause inadvertent damage to the urothelium if not carefully directed away. The field of view (depth of image) is limited compared with the rod–lens optical system of the rigid endoscope; thus flexible ureteroscopes are equipped with focusing mechanisms and image magnification to compensate for that loss. The ocular lens at the eyepiece produces a virtual image. The distance between the virtual image and the operator's eye is adjusted by the focusing control. Changing this distance compensates for any visual acuity differences between operators and allows for variation in the depth of field. The effect of image magnification depends on the distance from the object being viewed to the tip of the scope, with greater magnification produced the closer the object is to the distal tip [28].

Sheath dimensions

The working length of the newer flexible ureterorenoscopes ranges from 54 to 70 cm. The initial diameter of the flexible ureteroscope was significantly larger than the rigid scope and this necessitated that the ureter required ureteral dilation before its insertion. With time, the flexible ureteroscope has been streamlined and produced with a tapered shaft, allowing easier, less traumatic insertion. The tapering of the shaft usually leads to a flat, flush surface, though some scopes incorporate a beveled triangular design. Currently, the proximal shaft diameter can vary between 5.8F and 11F, and the tip diameter from 4.9F to 11F. Work by Hudson *et al*. showed that flexible scopes with a diameter less than 7.5F had a failure rate of approximately 1% compared with 15% for scopes with a diameter greater than 8.5F [45]. The use of a smaller diameter ureteroscope has also been associated with a reduction in ureteric complications.

Deflection mechanism

Active deflection of the tip of the ureteroscope is of fundamental importance to the success of diagnostic and therapeutic ureteroscopy [46]. Deflection of the thumb lever located on the hand-held portion of the ureteroscope places tension on control wires that run from here through movable metal rings within the shaft of the scope to the distal tip where the wires are fixed. The wires are effectively shortened by moving the control lever in order to get a range of deflection, which varies between scope models from different manufacturers. This results in tip deflection in the direction of that wire. Deflection in the opposite direction is accomplished by a wire on the opposite side of the ureteroscope. Control of the deflection lever is said to be "intuitive" when the tip moves in the same direction as the lever (an upward deflection on the handle lever deflects the scope upwards, and *vice versa*), or it can be "counterintuitive" (an upward deflection on the handle deflects the scope tip downward). Improvements in primary active deflection mechanisms now allow controlled deflection of the tip by up to 180° or greater, either up or down in the same plane.

Almost all current flexible ureterorenoscopes in addition to primary active tip deflection have secondary passive deflection where a proximal segment of the flexible ureteroscope shaft can become passively deflected on contact with the tissue (see Figure 34.7A). The passive segment is located just proximal to the point of active deflection, and is more flexible than any other part of the scope. The addition of secondary passive deflection allows lengthening of the deflected segment by moving the point of deflection more proximally, which effectively lengthens the tip of the shaft, permitting inspection and treatment of the entire intrarenal collecting system [23]. The main advantage of this design feature is to allow advancement of the tip of the ureteroscope into the lower infundibulum, allowing inspection of the lower pole calyces. Current flexible fiberoptic ureteroscopes all have enhanced active tip dual deflection in either direction with increased downward and upward deflection up to 270° (Figure 34.9). The maximal deflection is achieved using a single lever, which produces a broader radius of deflection, facilitating entry into the lower pole infundibulum. The ACMI DUR-8 Elite is unique in that it has two segments of active deflection to generate an enhanced tip deflection, which are operated by two levers found on the opposite sides of the ureteroscope handle (see Figure 34.7A).

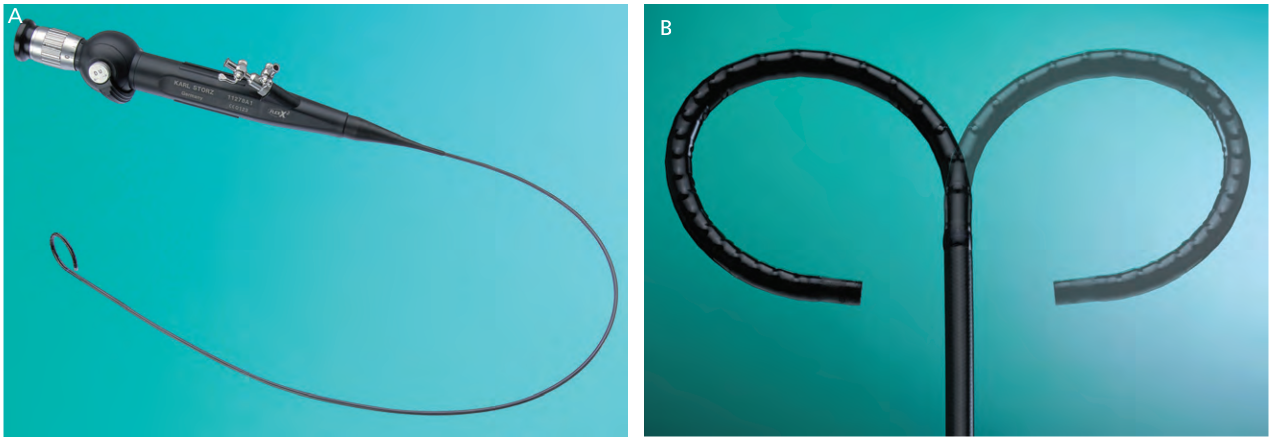

Figure 34.9 Karl Storz Flex-X2 ureterorenoscope with enhanced active tip deflection of 270° in both directions (courtesy of Karl Storz).

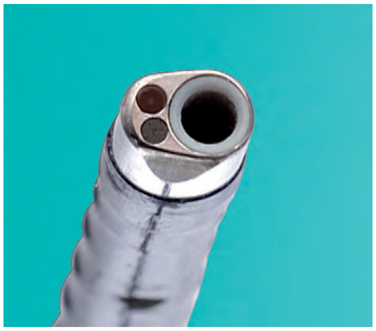

Figure 34.10 Tip design of the Flex-X2 ureteroscope demonstrating the ends of the optical system, light transmission bundle, and working channel (courtesy of Karl Storz).

Working and irrigation channels

The working channel was incorporated into the flexible ureteroscope in the 1980s, giving these scopes the ability to irrigate the field of view and pass instruments under direct vision, including laser fibers, electrohydraulic lithotripsy probes, biopsy forceps, stone baskets, and stone graspers, depending on the size and design of the working channel (Figure 34.10). The majority of the available flexible ureterorenoscopes have a 3.6F working channel, which allows the use of most accessory instruments that range in size from 3.2F to 1.5F. Larger 4.5F channels do currently exist and are specifically designed to accommodate a pneumatic contact lithotripsy flexible probe. However, with lasers fibers of diameters ranging from 150to 400 μm becoming increasingly used for contact lithotripsy, tissue destruction, incision, and fulguration, the requirement for ureteroscopes with working channels greater than 3.6F is questionable.

The working channel is formed from a smooth cylindrical plastic tube that travels the length of the shaft from the lower part of the handle to the tip of the scope, and is usually located eccentrically or offset at the tip. This eccentricity is less accentuated in the smaller-diameter ureteroscopes, because such a design causes less distortion of the working channel when the tip is deflected and allows for easier passage of working instruments [24]. Also, rotation of the ureteroscope may not be necessary when passing it through the ureteral orifice. The introduction of an endoscopic instrument into the working channel lumen invariably reduces active tip deflection and irrigant flow. For the newer small diameter flexible ureteroscopes, Chui *et al*. noted that deflection was less affected, though at the price of reduced rate of irrigant flow compared to older generation scopes [47]. The composition of the working instrument also appears to influence tip deflection, with stiffer accessories such as graspers and baskets composed of steel and polyamide resulting in reduced deflection capacity of the scope tip as compared to accessories made of either Teflon or nitinol. In a further study by Perry *et al*. [48], it was shown that the deployment of a 200-μm laser fiber in the working channel of a DUR-8 ureteroscope reduced primary deflection from 143° to 115°, while a 500-μm laser fiber reduced it further to 47°, but a nitinol accessory reduced it only to 123°.

Table 34.5 Irrigation flow rates for 3.6F working channels.

	Gravity (mL/min)	60 mL syringe (mL/min)	Roller pump (200 mmHg) (mL/min)
Empty channel	32–35	110	104
2.5F instrument	5–7	24–55	26
0.038-inch wire	2	21	N/A

In addition to reducing active tip deflection, the introduction of an instrument through the working channel will decrease the available lumen for passage of standard irrigation [49]. The use of smaller working instruments has again lessened the effect on flow reduction, and the use of higher-pressure irrigation as delivered by a pressurized irrigation bag, roller pump, hand-held syringe or bulb device (Bulbmaster), or foot-controlled device (Peditrol) can adequately compensate (Table 34.5). Flow rates of the order of 20 mL/min provide adequate visualization in most circumstances, though the downside of pressure irrigation is the increased risk of septic systemic complications from pyelorenal reflux, and the possibility of seeding tumur cells if present [50].

Column strength and tip deflection

The first flexible ureterorenoscopes had poor column strength and would buckle very easily [46]. As a consequence, the scope had to be passed through an access sheath or stiffened temporarily by placing a 0.035- to 0.038-inch wire either antegrade or by back-loading the rear end of the wire onto the tip of the scope. The latter technique had the potential to shorten the life of the ureteroscope and often required the active involvement of a primary surgeon and an assistant to facilitate passage of the instrument. The newer generation of flexible ureterorenoscopes has addressed this design issue and increased column strength, using improved proprietary polymers to give greater crush resistance as well as torque stability (Flex-X, Storz), while others have used a nitinol shaft design with a super slippery outer coating (DUR8-Elite, ACMI). The net result is a stiffer but torque-stable durable shaft, in essence producing almost a semi-rigid instrument but with a flexible deflectable tip.

Bends in the shafts of flexible ureterorenoscopes may severely restrict subsequent active tip deflection by as much as 61° [46]. In a study of scopes from all major manufacturers by Monga and Durfee, bending pressure was defined as the force required to deflect the tip of the ureterorenoscope by 15° from a baseline horizontal position [51]. These authors found bending pressure to vary from 6 g for the Wolf 7325.172 ureterorenoscope (7.5F), to 10 g for the ACMI DUR-8, to 12 g for the 9F Wolf 7330.072 instrument. Holding the instrument taut, placing a super-stiff guidewire in the shaft portion of the working channel, thus effectively stiffening it, or using an access sheath maximizes active deflection of the instrument tip. The insertion of a wire however, has to be balanced against the inevitable reduction in flow and vision, as well as hindering the possibility of injecting contrast down the working channel. The strength of the tip deflection, arbitrarily defined as the force that results in a loss of 10° active deflection, varies intrinsically from scope to scope [51] across a range from 46 to 265 g. As mentioned above, this figure can be limited by the additional rigidity of instruments within the working channel [34].

Light source

Light transmission to the tip of the scope begins with the source lamp. The most commonly used high-intensity light sources are halogen (150 W) and xenon (300 W)[28]. Such light sources have an automatic light-sensing feature, which can adjust the amount of light to the preset requirement of the camera. This function is particularly helpful during endoscopic procedures where different levels of illumination are encountered throughout the procedure. Alternatively, some digital cameras contain a light-sensing feature or automatic iris, which electronically increases or decreases the aperture of the camera shutter. With these cameras, there is no need for an automatic intensity-adjusting light source.

A flexible light cord, which is also made up of fiberoptic bundles, transmits the light to the ureteroscope. The light cord can either plug onto a post on the ureteroscope (a separate cord) or be incorporated into the ureteroscope (an integrated cord). The fiber bundles of an integrated light cord are continuous with the light bundle fibers travelling through the scope. A separate light cord will connect to a post on the scope to transmit light to the light fiber bundles. This connection invariably produces some loss of light power because of the inability to get perfect alignment of the fibers of the cord with those of the ureteroscope itself. This is usually not a significant problem because much more light is transmitted via the cord than is actually needed. The advantage of having a separate light cord is that only the cord must be replaced if it is damaged. One manufacturer of scopes (ACMI), using the separate cord arrangement, has patented a rotatable light cord connection post so that it can be rotated into a convenient place for the operator, whilst accessing the working channel.

Camera and video systems

The image seen from the ureteroscope can be either visualized directly by the operator's eye or by a range of cameras and monitors. Furthermore, the camera can be either fixed or free to rotate, with the image presented on the monitor orientated by the camera and not the endoscope. The top of the image on the monitor is therefore related to the top of the chip within the camera or in the ureteroscope. During cystoscopy, the image viewed at the eyepiece is readily orientated relative to the bladder and viewer. As the cystoscope is rotated, the trigone remains posterior and the dome of the bladder is at the top of the image. This same orientation is maintained with a rotating camera, which stays in one position relative to the patient. If the camera is fixed so it does not rotate but moves with the rotation of the cystoscope, as the cystoscope rotates 90°, the lateral wall of the bladder will appear at the top of the screen with the opposite wall at the bottom of the screen. This orientation occurs with the video chip cameras, which are fixed relative to the endoscope rather than the patient.

Traditionally, analog images have been transmitted through the fiberoptic bundles and converted into continuous waveforms before being displayed on an analog video monitor. Digital technology has revolutionized this process, as the digital image is not as susceptible to the degradation witnessed with the analog format. The digital format is ideal for taking digital still images and video, and this is an ideal format for storage. Current digital cameras capture the image on a CCD or CMOS chip. Each digital image is composed of millions of tiny dots of information or pixels. Each pixel corresponds to a charge generated by the CCD proportional to the light striking it. The pixels are then transferred to a storage element on the chip. The number of pixels and the number of CCD chips determines the resolution of the camera. The later cameras contain a prism-based-3 chip (multisensory) system, with a separate chip for each primary color (red, green, blue, RGB) giving a high-resolution output. The information from the three CCD sensors is processed and is amenable to modification by image processing software within the camera. The digital information is then transmitted to the television monitor to form a complete image. The original single-chip camera is less expensive and lighter, though it has poorer resolution.

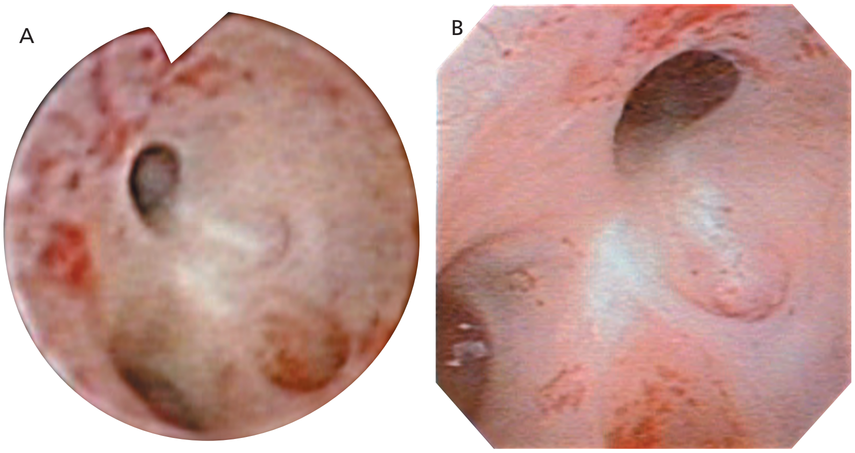

Figure 34.11 Comparison of image from fiberoptic ureterorenoscope versus Olympus URF-V Distal digital ureterorenoscope (courtesy of Olympus Medical).

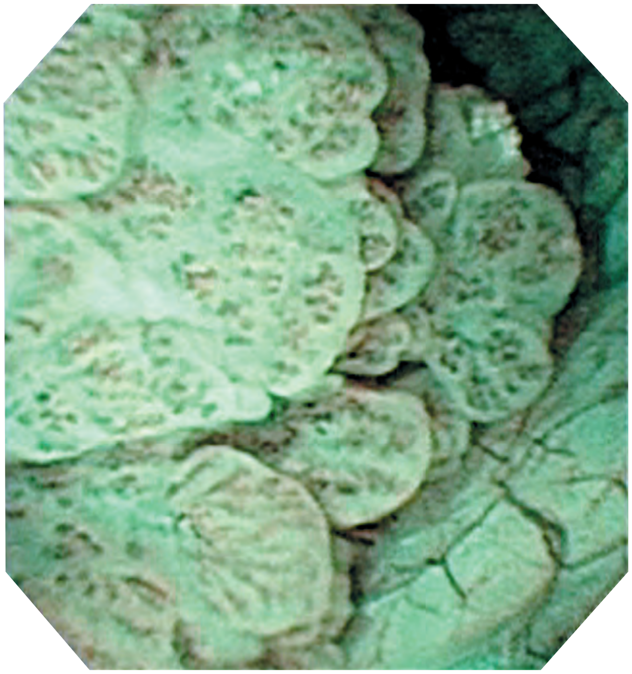

Figure 34.12 Narrow-band imaging as seen through the Olympus URF-V (courtesy of Olympus Medical).

Digital video ureterorenoscope ("chip on a stick")

Conventionally, optical images have been relayed from the objective lens at the distal end of the endoscope to a direct viewing lens and camera attached at the eyepiece. Instead of the rod–lens design or fiberoptic cables, a CCD sensor at the distal tip of the endoscope allows digitized information to be relayed back via a single fiber to a distant processor that reconstructs and digitally enhances the image electronically on a television monitor. The image quality is equivalent to ten times the pixel resolution of standard fiberoptic endoscopes (Figure 34.11). A further advantage of digital imaging is the ability to magnify an image up to 1.35 times. This technology has coincided with the arrival of high-definition digital television (DDV) to show the images to their full potential. It is envisaged in the future that further benefits will be gained as a result of losing the bundled fiberoptic cables, including smaller sized scopes, larger working elements, increased flexibility, and improved scope durability. The latest generation of digital ureteroscopes has already shown enhanced diagnostic capability with greater resolution of small mucosal lesions that could be missed with fiberoptic scopes.

Another function made possible by the use of a digitalization of the ureteroscope is narrow-band imaging (NBI) which is a feature specific to Olympus endoscopes. NBI is enabled with filters that restrict the wavelengths of light used for imaging to a narrow segment of the spectrum used in conventional white light endoscopy. To change from conventional white light endoscopy, the operator simply presses a switch on the endoscope to activate the optical filters. NBI is thought to enhance the appearance of both the epithelial surface and high-density microvessels associated with neoplasia (Figure 34.12). It is hoped that the sensitivity of detection of upper tract transitional cell carcinoma (TCC) may be improved using this technique, leading to earlier diagnosis, reduced recurrences, and long-term survival. Further clinical assessment is currently awaited.

Current ureteroscopes

The specifications of currently available flexible fiberoptic and distal sensor ureterorenoscopes are summarized in Table 34.6. Knudsen *et al.* performed a prospective multiinstitutional clinical trial randomizing patients to one of four available fourth-generation flexible ureteroscopes: the Wolf Viper, Olympus URF-P5, Gyrus-ACMI DUR-8 Elite, and Stryker Flex Vision U-500 [52]. The

Table 34.6 Specifications of currently available flexible ureterorenoscopes.

Model	Angle of view (degrees)	Field of view (degrees)	Length (mm)	Shaft diameter (F)	Tip diameter (F)	Channel size (F)	Active deflection up (degrees)	Active deflection down (degrees)	Location of passive deflection from tip (cm)	Secondary active deflection (degrees)
Olympus										
URF-P5	0	90	700	–	5.3	3.6	180	275	N/A	N/A
URF-V*	0	90	670	9.9	8.5	3.6	180	275	N/A	N/A
Olympus ACMI-GYRUS										
AUR-7	12 (air), 9 (fluid)	80	650	7.4	7.2	3.6	120	160	5	N/A
DUR8	12 (air), 9 (fluid)	80	650	8.6	6.75	3.6	175	185	6	N/A
DUR8-E	12 (air), 9 (fluid)	80	640	8.6	6.75	3.6	170	180	6	130
DUR-D*	0	80	650	9.3	8.7	3.6	250	250	N/A	N/A
Karl Storz										
Flex-X2	0	110	675	8.4	7.5	3.6	270	270	N/A	N/A
Flex-X^{C}*	0	90	700	8.5	8.5	3.6	270	270	N/A	N/A
Richard Wolf										
Viper	0	86	680	8.8	6	3.6	270	270	N/A	N/A
Cobra	0	85	680	9.9	6	3.3	270	270	N/A	N/A
Stryker										
FlexVision U-500	0	90	640	–	6.9	3.6	250	250	–	80

*Distal sensor digital ureteroscopes.

ACMI DUR-8 Elite and the Stryker Flex Vision are unique in offering an active primary and secondary deflection mechanism activated by a dual lever mechanism found on the ureteroscope handle. The Dur-8 Elite has a maximum unidirectional down deflection of 315° when both levers are activated (see Figure 34.7A). It must be noted that if the point in the shaft where secondary active deflection is controlled is too far proximal from the tip, it may be fixed in the upper ureter at or below the UPJ, and this may negate any possibility to gain extra primary or secondary active deflection. The Flex Vision U-500 has bidirectional deflection of greater than 270°. Of the other two ureteroscopes examined, the Olympus URF-P5 has an upward deflection of 180° and a downward deflection of 270°, whereas the Wolf Viper offers active deflection of 270° in both directions. The Flex X2, which was not included in the study, has bidirectional primary deflection of 270° (see Figure 34.9). Although the Olympus, Wolf, and Stryker scopes showed similar durability, the group found that the Wolf Viper had better visibility and maneuverability ratings when compared with the other scopes. This finding is consistent with previous studies and is thought to be due to the Wolf's unique fused quartz bundle optics.

Given the potential advantages of the digital ureteroscopes, it is hard to envisage that the fiberoptic instruments will remain in circulation beyond the next decade. The two flexible video ureterorenoscopes currently commercially available are the Olympus URF-V, which utilizes a CCD chip and has the optional NBI function, and the ACMI DUR-D which incorporates CMOS chip technology (Table 34.6). Karl Storz has introduced the Flex X^C video-ureterorenoscope, which has the CMOS chip at the tip along with the Laserite thermal damage protection technology employed in the previous generation of Storz flexible ureteroscopes (Table 34.6).

Multescu *et al*. compared the Olympus URF-V digital flexible ureteroscopes with the Storz 11274AA flexible fiberoptic scope [53]. The group compared maneuverability, visibility, inferior calyx approach, maximal tip deflection and irrigation flow, and endoscopes fragility. The distal sensor ureteroscope scored higher on maneuverability and visibility, and had minimal loss of tip deflection on instrumentation when compared with the fiberoptic scope. Furthermore, superior rates of irrigation flow were seen for the digital flexible scope both with and without instruments placed down the working channel. The only downside to the Olympus URF-V was the larger distal tip of the scope that may reduce its accessibility to narrow segments of the collecting system.

Flexible ureterorenoscope technical failure

The flexible ureterorenoscope by nature of its function requires more working parts than the semi-rigid scope. Over the years this has led to issues regarding their reliability and concerns over the regularity of costly repairs that can often be time-consuming. Although reliability has improved following a greater understanding of the mechanisms leading to scope failure [54], the ureteroscope of the future needs to be increasingly robust to meet the rigors of frequent daily use and to prevent costs from escalating. Factors that have been considered to be significant in technical failure of the ureteroscope have included: features inherent to the design of the flexible ureteroscope, complexity of the endourology procedure, experience of the surgeon and personnel assisting the case, the techniques adopted for the procedure [55], and the sterilization process [56].

The introduction of lasers for contact lithotripsy, tissue destruction, incision, and fulguration has significantly increased the usefulness of the flexible ureteroscope, and a study by Pietrow *et al*. has shown that this has increased the longevity of the flexible ureteroscope [57]. The use of the laser can, however, potentially shorten the ureteroscopes working life due to damage of the working channel from use of the laser fiber when the tip is located close to the end of the ureteroscope or from laser malfunction. The main risk of *in situ* fragmentation of stones with a maximally deflected scope tip is unseen damage to the inside of the working channel at the point of maximum deflection, owing to energy released from microfractures of the stiff quartz core material. In most instances, this damage will not be discovered until after the scope has been sent for sterilization prior to next use, but may be suspected if there is no visible response of the target to energy discharge after foot–pedal activation. In general, it is better to relocate the stone into a more favorable position (upper or middle calyx) within the kidney or into the ureter (for smaller stones) before it is treated, if the life of the flexible ureterorenoscope is to be maximized. The practice of back-loading the ureteroscope onto the stiff rear end of the working wire can also lead to a hole being punctured in the working channel lining, raising an invisible internal flap that may prevent the subsequent passage of any additional accessories during the rest of the case.

The active deflection unit is the most fragile part of the flexible ureteroscope, with studies showing that deterioration in active deflection up to 28% can occur in instruments smaller than 9F in consecutive use [58]. Degradation in this unit or rough handling of the shaft can then lead to knock-on effects on the fiberoptic bundles. Even though the optical fibers are flexible, they are also quite delicate and may be damaged by excessive force or pressure on the shaft of the scope. An excessive force on the ureteroscope can develop when an extreme deflection force is attempted by the operator or alternatively when the turning circle of the deflectable tip is greater than the size of the renal pelvis, which is not sufficiently capacious to accommodate the instrument. A prolonged approach to the lower pole calyx can also lead to a loss in deflection.

The estimated number of procedures that can be undertaken before the flexible ureteroscope requires a major repair has improved over the years from around 15 (or 13 h of usage) to approximately 50 [58, 59]. The need for repair occurs less frequently with the newer generation endoscopes and when the surgeon is more experienced. In the latest offering of flexible ureterorenoscopes from Storz, the Flex-X2, the working channel has a 1.5-cm ceramic-coated distal tip. This aims to protect the channel from damage when the laser is placed close to the tip of the scope. This instrument also incorporates a shock absorbing mechanism at the scope's deflecting segment. The durability of the current generation of scopes with exaggerated active deflection from other major companies (Olympus URF-P5, Gyrus ACMI DUR-8 Elite, and Stryker Flex Vision U-500) was recently assessed by Monga *et al*. [52]. The study aimed to see whether technologic progression in ureteroscope design translated to an improvement in durability. It was concluded that the DUR-8 Elite faired well in the clinical trials, yet this was at the expense of a major repair being necessary after the fewest average number of cases. The emergence of the digital flexible ureterorenoscope has offered the possibility of improved durability. Multescu *et al*. recently compared the current Storz fiberoptic ureteroscope with the Olympus URF-Vo digital endoscope and found that the digital set-up appears more robust with no loss of deflection encountered after 22 procedures [53].

Care, maintenance, and sterilization

Care of the small-diameter flexible ureteroscope begins with careful handling. In transit, the endoscope should be coiled loosely and not be bent as the glass optical fibers can easily be damaged. On handling, the scope should be held by the handpiece with the tip in a dependent position. Prior to insertion, the instrument should also be examined to ensure that all deflecting cables operate properly and that the tip can be deflected to the recommended extent in each direction. The operator should also check for optic fiber damage before and after each use, with broken fibers appearing as small black dots within the image. When over 20% of the fibers are broken, the ureteroscope should be sent for repair, as adequate light can no longer be transmitted. A light meter is needed for exact measurement. The optical fibers that transmit the image should also be checked both before and after each use. This is done by holding the scope tip close to the target object. If the image appears cloudy, the endoscope may need repair owing to moisture leaking into the optical fibers, which often occurs as a result of a breach of the working channel by a stiff guidewire or fractured quartz laser fiber. This ritual should again be repeated at the end of the operation.

During the case, the durability of the flexible endoscope can be improved by taking preventative measures to eliminate inadvertent damage from a laser fiber and by avoiding over deflection. With the use of instruments, iatrogenic scope injury can be avoided by straightening the tip before advancing the accessory through it, and the liberal use of jelly or silicone lubricant (e.g. Glide) to reduce frictional forces, though the working channels is some of the most recent models (e.g. DUR-8) have a slippery lining (e.g. DUR-8). Other methods for improving the longevity of the flexible ureterorenoscope have included routine use of ureteral access sheaths, nitinol devices, and 200-μm holmium fibers [57]. Having finished with the scope, further care must be taken in the sterilization of these delicate instruments. Ureteroscopes should be cleansed with warm water and a nonabrasive detergent to remove any debris following use (see Chapter 1). The working channel should be washed with a flow of water. This initial cleansing may be the most important step in the care and sterilization process [60]. Flexible endoscopes can then be sterilized by gas (ethylene oxide) or disinfected by soaking in a glutaraldehyde solution [60, 61]. Another option is the Steris system (Mentor, OH, USA). This system provides automated washing and rinsing of the endoscopes with a peracetic acid solution, which will sterilize immersible instruments in 30 min.

The control bodies and light guide connectors of modern endoscopes are constructed with a water-impermeable seal to protect the optical systems and working mechanisms from fluid or moisture seeping damage, and should be leak-tested before and after every procedure. During gas sterilization, changes in the temperature surrounding the endoscope can cause significant pressure changes within the sealed portion of the scope. A venting system, such as a valve on the light post, is important to equalize pressures during gas sterilization and prevent damage to the scope. Alternatively, some scopes have a more solid core with no internal air spaces, which then do not require an internal venting system.

Composite ureteroscopes

The cost-effectiveness of the flexible ureterorenoscope given the initial financial outlay and cost of repairs can be a significant burden to a urology department [62]' especially in developing countries. The cost of carrying out 100 ureteroscopic procedures was estimated to range from US$31 500 to $60 000 in a study performed by Landman *et al*. [63]. Sun Yinghao *et al*. envisaged that a hybrid ureteroscope with a rigid shaft combined with a deflectable tip might have a longer life-expectancy, which would benefit economically undeveloped countries in particular [64]. With technical help from Olympus, a rigid ureteroscope with the flexible tip of the Olympus URF-P3 flexible ureteroscope was fashioned. In total, 175 patients with renal calyceal calculi underwent deflectable tip rigid ureteroscopic lithotripsy with a holmium laser with a success rate of 83% stone clearance at 1 month. This new ureteroscopic technique was seen to have some definite advantages when compared with other types of traditional stone treatment. First, patients requiring ureteroscopy for stones in two different locations can have them treated with a single composite ureteroscope. Second, the tip of the ureteroscope can be controlled and orientated by manipulation of the rigid shaft. For some patients however, it was difficult to enter the renal calyces because of the short 60 mm length of the flexible ureteroscope tip. They concluded that ureteroscopic lithotripsy using the novel hybrid design is a safe procedure and combines the advantages of rigid and flexible ureteroscopy, especially for renal calculi of relatively small size.

Disposable ureteroscopes

Technical failure of the flexible ureterorenoscope most commonly occurs in the region of the active deflection unit and once damaged, the ureteroscope, if repairable, will require either a costly fix or even a replacement. It is therefore conceivable that an inexpensive, small caliber, disposable flexible instrument with similar deflection capabilities might decrease the initial outlay and overall investment. In 1987, Bagley reported the use of a flexible modular ureteropyeloscope in 38 patients [65]. The flexible tips of the ureteroscope were made available in 6F, 8.5F, and 11F, and all were replaceable. The instrument was successfully passed into the ureter in all but one patient, supporting the wider application of the equipment. Over two decades later, Boylu *et al*. published their findings comparing mechanical and optical properties and flow rate of the disposable flexible SemiFlex Scope (MariFlex, Baton Rouge, LA, USA) with six established, commercially available ureteroscopes [66]. The disposable ureteroscope consisted of a reusable eyepiece and semi-flexible shaft with a 3.5F working channel. The results showed that the disposable flexible ureteroscope had the highest active tip deflection, though the downside was that it had the greatest reduction in deflection with the introduction of a working instrument. The purchase price was, however, significantly lower and no further expenses were incurred. More recently, the Polyscope (PolyDiagnost, Pfaffenhofen, Germany), a steerable endoscopic catheter system with single-side active deflection, has been trialed [67]. In this early fit for purpose clinical evaluation, the Polyscope appeared easy to use, effective, and reliable, and may provide a financial answer to the inherent frailties of nondisposable scopes.

Future trends

The digital video endoscope is now here to stay and the endless possibilities using this technology are just starting to be realized. With further improvements in materials and endoscope design, the ability of the endourologist of tomorrow to diagnose and treat pathologic conditions affecting the urinary tract will continue to improve. It will not be long before all major endoscope manufacturers produce a distal sensor ureteroscope, and the endoscope of the future, whether rigid or flexible, will contain no viewing lens component. Further progress in digital technology will ensure further reductions in shaft diameter and the addition of increased functions, including wireless transmission of images to high-definition PC monitors, and potentially portable ureterorenoscopes. It remains to be seen whether these changes will result in improved durability. Robotic ureteroscopy is discussed in Chapter 48.

Three-dimensional ureteroscopy

Current endoscopic systems provide an image output in two dimensions with stereoscopic or three-dimensional (3D) imaging existing only in the domain of robotic and, rarely, laparoscopic surgery. With miniaturization of the CCD chips and future reduction in the cost of this technology, positioning two of them in the distal tip of the scope would enable stereoscopic images to be created with true depth perception. The advantages of 3D imaging during ureteroscopic procedures however, have not been confirmed and the additional costs may not be offset if the benefits prove to be small.

Virtual ureteroscopy

The use of virtual endoscopy for computer-driven reconstruction has been applied to multiple sites in the human body where there is a hollow viscus, including the renal collecting system and ureter [68, 69] (Figure 34.13). Although it is early days for this technology, this technique may prove to be useful as a noninvasive way of surveilling the urinary tract.

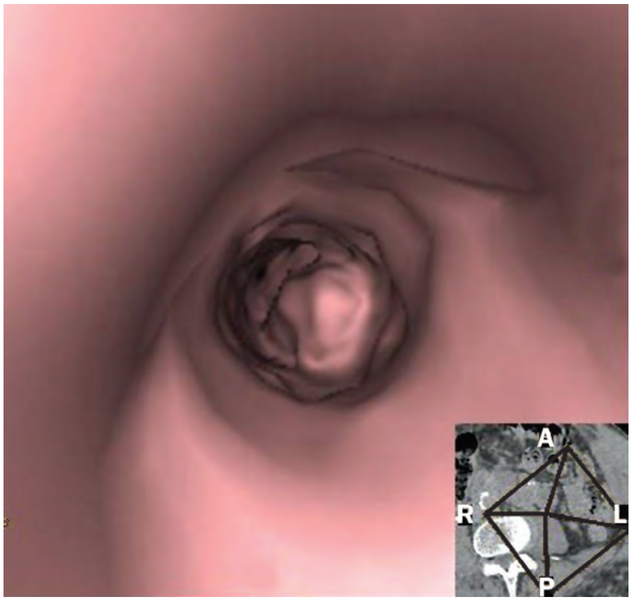

Figure 34.13 Computed tomography (CT) virtual ureterorenoscopy image created from a CT scan showing a urothelial tumor (courtesy of Nature Publishing Group).

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CHAPTER 35

Ureteroscopy Working Instruments

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Introduction

Before the birth of Endourology in the early 1980s, upper urinary tract diseases were managed through large open incisions, which were associated with significant associated patient morbidity [1]. The advent of flexible and semi-rigid ureteropyeloscopy has lead to less invasive treatment options for the upper collecting system. Over the course of time, lead by the interaction between engineering and medicine, the instrumentation and technique of endourology has continued to be refined and improved.

Patient preparation

After induction of anesthesia, the patient is placed in a lithotomy position with the ipsilateral leg slightly extended [2]. Though recommended primarily for patients with a moderate risk of thromboembolism [3], we routinely utilize pneumatic compression boots in all patients in the lithotomy position to decrease the risk of deep venous thrombosis and of intracompartment pressure [4].

The C-arm monitor, video monitor, and holmium laser machine are positioned on one side of the patient such that little movement by the surgeon is required to view the C-arm and endoscopic images, or operate the laser foot pedal. It is helpful to utilize software that draws the fluoroscopic image into a "picture-in-picture" format on the endoscopic image. Typically a flat-screen monitor mounted on a swivel-arm is utilized. The C-arm device is positioned on the other side of the patient to allow for free movement of the image intensifier from the kidney to the pelvis.

On occasion, if there is uncertainty as to whether the pathology may require a percutaneous approach, the patient may be positioned in a prone split-leg position, so that it is easy to proceed with posterior percutaneous renal access if needed [5].

Ureteral access

The use of a safety wire is encouraged for all urologic endoscopic procedures, though some authors suggest it is not needed if active stone basketing is not planned as part of the procedure [6]. Guidewires facilitate and maintain access to the upper urinary tract and may straighten an otherwise tortuous path. The ideal guidewire would require little force to bend in response to obstruction, and a large force to perforate through tissue. These properties were examined in an *in vitro* study of nine commercially available guidewires, and the lubricous, soft-tip nitinol glidewire (Boston Scientific, Natick, MA, USA) was the safest wire for initial access to the ureter, as it is less likely to perforate and more likely to bend at a point of obstruction [7].A standard guidewire would also have a fairly stiff mid-shaft to straighten the ureter and facilitate coaxial passage of other devices (sheaths, stents, etc.). It would have a floppy tip on the external end to facilitate atraumatic

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back-loading of the flexible ureteroscope if needed. The Bard Sensor guidewire (Boston Scientific) is a hybrid wire that combines these components; a hydrophilic distal tip, shift shaft (nitinol core with polytetrafluoroethylene coating), and floppy proximal tip [8]. We typically utilize a 0.035-inch Sensor guidewire initially to cannulate the ureteral orifice and advance up to the level of the renal pelvis. If resistance is encountered, a 5F open-ended catheter is advanced to the level of resistance under fluoroscopic guidance and retrograde pyelography is performed to delineate the ureteral anatomy. A 0.035-inch straight-angle hydrophilic glidewire (Boston Scientific) is then placed through the open-ended catheter and advanced beyond the site of obstruction. For coaxial passage of ureteral access sheaths and large caliber stents and catheters, an Amplatz super-stiff guidewire kinking (Boston Scientific) is utilized to minimize the risk of wire buckling.

Torqueable catheters

At times the ability to guide a wire past a point of particular tortuosity may prove beneficial to establish secure guidewire access. One alternative would be to utilize an angled-tip guidewire and a torque device which attaches to the external end of the wire. Rotating the torque device reorients the tip of the wire to direct it towards the anticipated path of the lumen as outlined on retrograde pyelography. Alternatively, a variety of torqueable angled catheters (Kumpe, JB-1, Cobra) can be utilized to help guide the wire in the correct direction.

Ureteral access sheaths

Ureteral access sheaths facilitate expeditious and atraumatic entry and re-entry to the upper collecting system with the flexible ureteroscope, while eliminating the risk of buckling of the endoscope in the bladder. The use of a ureteral access sheath has been demonstrated to decrease operative time and cost, minimize patient morbidity, and optimize overall success of flexible ureteroscopy [9]. Specifically, a retrospective case series has demonstrated superior stone-free rates in a contemporary series of patients undergoing ureteroscopy with the use of an access sheath compared to no access sheath [10].

The access sheath also protects the upper urinary tract from increased peak intrarenal pressure, even with irrigant pressurized to 200 cmH_2O, as it allows efflux of irrigant through the sheath and around the ureteroscope, maintaining intrapelvic pressures below 20 cmH_2O [11].

Finally, some authors have suggested that the use of a ureteral access sheath decreases the risk of endoscope damage [12].

In vitro and randomized clinical studies have demonstrated that the Cook Flexor sheath (Cook Urological, Bloomington, IN, USA) is superior with regards to ease of placement, instrument passage, and stone extraction [13], is more resistant to both buckling at the ureteral orifice and kinking after removal of the inner dilator [14], and has one of the largest inner diameters in the most common positions of straight and 30° bends, which further facilitates stone extraction [15]. Recently, when compared to the next-generation of ureteral access sheaths, the Cook Flexor remained the most resistant to buckling, though the Gyrus-ACMI Uropass (Gyrus ACMI, Southborough, MA, USA) was more resistant to kinking [16].

A 12/14F ureteral access sheath is the standard size utilized for adults, as studies have demonstrated that this internal diameter optimizes irrigant flow and intrapelvic pressures [17]. Typically, a 35-cm length sheath is utilized for women and a 45-cm length sheath for men if the goal is to reach the ureteropelvic junction (UPJ). If the sheath does not go up the ureter, the inner dilator can be used without the outer sheath to dilate the ureter over a super-stiff guidewire. If unsuccessful, a ureteral balloon (see below) through the sheath may be used or a ureteral stent placed to passively dilate the ureter.

Intracorporeal lithotrites

While a number of different endoscopic lithotrites, such as ultrasonic, electrohydraulic (EHL), pneumatic, and laser have been utilized for ureteroscopic lithotripsy, the holmium laser has become established as the standard of care due to its efficiency, versatility, and safety. *In vitro* analyses have demonstrated that the holmium laser fragments all stone compositions and produces smaller stone fragments than pneumatic, EHL, and pulsed-dye (Candela) lithotripsy [18]. While EHL can cause damage even if fired several millimeters away, the holmium laser can be safely activated at a distance of 0.5–9 mm from the ureteral wall without risk of perforation as the energy is effectively absorbed in a fluid medium [19].

Holmium:YAG laser lithotripsy generates a photothermal process that leads to direct absorption of the laser energy by the stone and thermal combustion. It also creates a vaporization bubble that subsequently destabilizes and decomposes the stone [20]. In clinical trials the stone-free rates both at the end of the ureteroscopy and 3-months post procedure were significantly higher for the holmium laser than either EHL [21] or pneumatic lithotripsy [22].

Laser energy is brought to the target (stones) with the aid of laser fibers, which are thin and flexible, optimal characteristics for passing through the working channel of a flexible ureteroscope. Studies on performance and safety of commercially available holmium laser fibers demonstrated that the Dornier Lightguide 200 was the most likely of the small fibers (200–273 mm) to fracture and damage a flexible ureteroscope, while the Lumenis 272 (Coherent, Santa Clara, CA, USA) and the Innova Quartz 400 (Gyrus-ACMI) were the most durable in their size class [23].

The 365-μm laser fiber is more durable and results in the best stone fragmentation efficiency [24]. However, the increase in size leads to a decrease in active deflection of the flexible ureteroscope; only 7–16% of maximum deflection (–9° to –19°) is lost with the 200-μm fiber compared to 18–37% (–24° to –45°) of maximum deflection with the 365-μm fiber [25, 26].

Pneumatic lithotripsy has the advantage, especially in areas where resources are limited, of low maintenance and disposable costs. The disadvantages of pneumatic lithotripsy are the increased risk of stone migration and the inability to apply this modality through a flexible ureteroscope.

EHL generates a spark which results in plasma expansion at supersonic speed, propagating a hydraulic shock wave and cavitation bubble. Collapse of the cavitation bubble leads to a second shock wave, which if asymmetric leads to the formation of a liquid jet. Each of these mechanisms results in stone fragmentation [27, 28]. However, the safety of the device is the primary concern, with one series reporting a 3% conversion rate to open surgery due to ureteral perforation in conjunction with a stone-free rate of only 58% at 3 months [29].

Ureteral occluding devices

A variety of devices have been developed to prevent stone migration during intracorporeal lithotripsy. The Stone Cone (Boston Scientific) consists of concentric coils which act to prevent proximal retropulsion of stone fragments, and it has proved to reduce the incidence of residual stone fragments greater than 3 mm in size [30]. The 2.8F Cook N-Trap (Cook Urological) is composed of 24 interwoven nitinol wires and in *ex vivo* pig ureters has been shown to prevent the migration of plastic beads as small as 1.5 mm [31]. Each device is designed to release any larger fragments as the device is withdrawn. It has been demonstrated that the Stone Cone releases the stone with a mean force of 0.19 lb and the N-trap with a mean force of 0.86 lb, suggesting a potential safety advantage with the Stone Cone [32]. More recently, the Percsys Accordion (Percutaneous Systems, Palo Alto, CA, USA) has been launched into market and proved in an *in vitro* comparative study to be as safe and efficient as the Cook and Boston Scientific counterparts [33].

In vitro studies have evaluated a biogel polymer that is delivered using a 3F ureteral catheter above the stone to occlude the more proximal ureter. The triblock polymer of polyethylene oxide is a liquid at low temperatures and turns into a gel at body temperature. Warm irrigation must be utilized during the procedure, then cold saline is instilled to liquefy the polymer at the completion of lithotripsy. Residual polymer dissolves in urine after 2 h and is expelled [34]. In a recent randomized clinical trial, Rane *et al*. reported the successful use of a water-soluble polymer (BackStop) to prevent stone migration during semi-rigid ureteroscopy. The study showed that this polymer was efficient in stabilizing the stone during laser or pneumatic lithotripsy; moreover, no adverse events were associated with its use compared to conventional ureterolithotripsy [35].

Each of these devices and techniques requires additional manipulation prior to ureteral lithotripsy, so the benefit of their use should be weighed against the additional risks of perforation in the face of a large ureteral stone. Specifically, their use may be most warranted in situations where pneumatic lithotripsy is planned and the risk of migration is higher, or if there is significant hydroureteronephrosis above the stone, or if there is limited availability of flexible ureteroscopy to retrieve stones that migrate.

Stone retrieval devices

A stone retrieval device is an essential instrument in ureteroscopy. Each device can be evaluated and distinguished by its ability to be visualized during stone manipulation, to provide radial force to open in the ureter, and to capture, retain, or, if necessary, disengage a stone. Alligator or rat tooth forceps are preferred by some due to their reversible grasp and reusability; however, their large size and weak grasp impact their effectiveness [36].

Nitinol-based baskets are more versatile due to the unique pliability of the wires and the flexibility that allows full lower pole deflection of a flexible ureteroscope in the majority of cases [37, 38]. *In vitro* studies have shown that the Cook NCircle 2.2F (Cook Urological) was the most efficient in capturing stone from a ureteral model, while the Sacred Heart Halo 1.5F (Sacred Heart Medical, Minnetonka, MN, USA) was the most efficient compared to 12 other baskets in a calyceal model [39–41]. If there are stone fragments adherent to the renal papilla, the Cook NCircle 2.2F basket wires are more pliable and can be distorted with gentle pressure until they embrace and grab the adherent stone fragments.

The Cook N-Compass (Cook Urological) with its webbed configuration is designed to optimize the retrieval of multiple small (1 mm or less) stone fragments that may result from lithotripsy of a large burden intrarenal stone.

The Bard Dimension basket (Boston Scientific) has a unique lever that extends two wires to “deflect” the cage of the basket. It has been proposed that this facilitates retrieval of stones in hard to reach calyces and stone release if needed [42]. However other investigators have reported that this affords no advantage for either stone capture or release [43]. The Boston Scientific Graspit and Cook NGage are two devices that have coupled the properties of a three-prong grasper with the entrapment capability of a regular tipless nitinol basket. It has been proposed that they provide a better ability to grasp and release the stone [44].

The 1.5F Sacred Heart Halo has been demonstrated to be the most efficient at stone retrieval of smaller fragments and provides superior irrigation compared to the Microvasive Zerotip 1.9F (Microvasive Urology, Natick, MA, USA) [45]. In addition, it allows rotation of an engaged stone via a rotary wheel on the basket handle, and simultaneous laser lithotripsy, as a 200-μm laser fiber can be passed alongside the Halo basket; a technique that is utilized if a stone is too large for removal down the ureter. The 1.9F Escape nitinol stone retrieval basket (Boston Scientific) offers the same property of "side by side" approach, preventing retrograde ureteral stone migration [46]. These two devices are of particular interest in cases of entrapped ureteral or renal stones where laser lithotripsy prior to stone capture cannot be accomplished. Recently, the 1.3F Optiflex basket (Boston Scientific) has been released, and this is currently undergoing evaluation.

Ureteral balloon dilators

Ureteral balloon dilation is utilized in approximately 5% of cases, when the ureteral access sheath will not advance to the site of pathology due to ureteral stricture, spasm, or a tight ureteral orifice. Ideally, a ureteral balloon would dilate to 100% of the expected diameter regardless of any amount of radial constrictive force. An *in vitro* study compared the dynamics of ureteral balloon expansion under varying extrinsic compressive forces and inflation pressures [47], and concluded that at inflation burst pressure, the Cook Ascend AQ (Cook Urological) was the most reliable balloon, achieving and maintaining over 100% of the expected inflation diameter with minimal pressure and a small coefficient of variation. The Bard X-force balloon dilator, the only balloon rated to 30 atm inflation pressure, was not evaluated in this study.

Flexible ureteroscopes (see also Chapter 34)

Current flexible ureteroscopes offer increased lower pole access through exaggerated active deflection compared to older passively deflecting scopes. Some achieve this by incorporating separate dual-lever primary and secondary active deflection that offers increased unidirectional downward deflections of 270° (Gyrus-ACMI Dur8-E, Stryker Flexvision). Other endoscopes provide increased bidirectional primary deflection of up to 270° using one deflection lever (Gyrus-ACMI Dur-D, Olympus URF-P5, Karl Storz Flex-X2, Richard Wolf Viper). Recently, a dual-channel flexible ureteroscope, Wolf Cobra (Richard Wolf Endoscopy, Vernon Hills, IL, USA), has been developed that affords the opportunity to hold traction on soft tissue while transecting the tissue with a laser, or the ability to hold a stone in a basket while laser ablating through the second channel. This endoscope offers superior deflection and irrigation characteristics, in particular when larger 2.4F accessory instruments are utilized [48].

A comparative study of available flexible ureteroscopes showed that the Wolf Viper provides superior irrigant flow, and better visualization through the unique fused quartz bundle compared to glass fiberoptic bundles [49]. Moreover, the Wolf Viper 7.5F (Richard Wolf Endoscopy) was shown to have a twofold greater resolution than the other flexible fiberoptic ureteroscopes, and *in vitro* evaluations of scope manipulation have demonstrated that it is superior at accessing all calyces in a hydronephrotic kidney model [50].

Another critical consideration is the durability of the flexible ureteroscope. Afane *et al*. were the first to note that although the flexible ureteroscopes were highly efficient in diagnosing and treating upper tract abnormalities, after only 6–15 uses they needed to be repaired, mostly due to problems in the deflection unit [51]. Subsequently, a randomized prospective multicenter study demonstrated that the Gyrus-ACMI DUR-8-Elite was the most durable flexible ureteroscope circa 2005 [52]. The most recent randomized clinical study of the next generation of flexible ureteroscopes demonstrated that the Wolf Viper, Olympus URF-P5, and Stryker Flexvision U-500 flexible ureteroscopes appeared comparable with regard to durability, suggesting that some parity has been achieved between manufacturers [53].

Modern digital flexible ureteroscopes (Olympus URF-V, ACMI DUR-D) offer improved ease of handling and visibility as they have eliminated the light cord and improved optical resolution with complementary metal oxide semiconductor (CMOS) technology. Digital scopes employ the light emitting diode (LED) technology, a durable and cheap cool light, putting aside the traditional xenon light, an expensive and less durable heat-generating light source. The absence of optic fibers in the shaft of the flexible scope allows for better deflection and simplifies the instrument, which may lower costs, and improves maneuverability and durability [54]. However, Knudsen *et al*. recently reported that the distal lens of the digital ureteroscope appears to be extremely fragile and prone to breakdown, in contrast to what had been previously reported. The authors concluded that to improve reliability and cost-effectiveness, refinements of the digital scope design are still required [55].

Disposable flexible ureteroscopes

A new cost-effective technology is available for retrograde access to the upper urinary tract, based on the premise of a single-use flexible endoscope, which eliminates the need for sterilization between cases. Basically, the disposable flexible ureteroscope comprises a reusable 10 000-pixel fiberoptic attached to a hand-held with a deflection lever, detachable light source, and irrigation source. For every new case a sterile 8F sheath is snuggly advanced over the fiberoptic shaft, keeping the later from touching the patient. This sterile sheath contains a 3F working channel and is capable of being deflected along with the fiber optic. Recently, it was reported by Boylu *et al*. that this new modality of endoscope has acceptable active tip deflection, field of view, and flow rate compared to six other flexible ureteroscopes on the market [56]; however, it is advised that this disposable ureteroscope is used for simple clinical cases, reserving the traditional reusable flexible ureteroscopes for more complex cases.

Endoirrigation systems

The passage of instruments through the working channel of a flexible ureteroscope can significantly decrease irrigant flow and result in poor visualization. Gravity with or without the assistance of pressure-bag compression is commonly utilized. With the use of a ureteral access sheath, intrarenal pressures can be maintained below 30 cmH_2O even with systems pressurized to 200 cmH_2O [57]. Alternatively hand-held, foot pedal, or automated irrigation systems may be utilized.

An automated irrigation/suction system (Endo-FMS Urology, Future Medical Systems USA, Glen Burnie, MD, USA) incorporates an irrigation roller pump with a suction roller pump (functional during rigid ureteroscopy only) to provide continuous flow and a controlled pressure. The Peditrol (EMS Medical Systems, Stroud, UK) is a foot pedal syringe-based irrigation system that functions by two separate one-way valves, one attached to gravity or a pressure bag and the other attached to a 3-mL syringe secured to the Peditrol foot pedal. The Boston Scientific single-action pump is a 10-mL vacuum syringe that has one-way valves that provide automatic refill of the syringe for immediate access to irrigation fluid.

Recently, an *in vitro* study evaluated the impact of stone migration with each system as well as the efficiency of irrigation to clear the operative field of blood, as measured by number of pulses and duration of irrigation. Of the hand-held devices, the single-action pump exerted the least impulse on a stone, decreasing the likelihood of dislocating the stone during the endoscopic surgery [58]. Though pressurized saline bags were not as efficient at clearing the operative field, they did result in less migration than hand-held or foot pedal devices.

Future innovations

Future innovations may lead to higher stone-free rates. Investigators are developing iron-oxide microparticles that bind to the calcium component of stones and provide the opportunity for expeditious extraction with a magnet-tip retrieval device [59].

Alternatively, future innovations may lead to a safer procedure. The addition of isoproteronol (a ß1,3-adrenoreceptor stimulant) to the irrigating solution during ureteroscopy relaxes the ureteral smooth muscle, leading to lower intrarenal pressures, which and may facilitate the passage of fragments, debris, or clot [60].

These are a few futuristic concepts that may lead to better outcomes for the patient and facilitate the procedure for the endourologist. Driven by innovation, endourology will remain a dynamic field, with evolving improvements towards the best clinical practice.

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CHAPTER 36

Access to the Ureter: Rigid Ureteroscopy

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Introduction

Technologic advances that allowed for downsizing of endoscopes, bigger working channels, improved working elements and video, and the advent of the holmium laser have revolutionized upper tract endoscopy and positioned it as a key diagnostic and therapeutic tool in the urologist's armamentarium.

Indications for distal ureteroscopy

The ureter is divided into proximal, mid, and distal segments. The proximal ureter extends from the ureteropelvic junction (UPJ) to the iliac crest. The mid-ureteral segment overlies the iliac wing. The distal ureter is defined as the segment distal to the pelvic brim and iliac vessels. Its intramural portion is fixed and narrow, and must be manipulated with care to avoid iatrogenic insults.

A semi-rigid endoscope usually grants easy access into the distal ureter and on occasions it can be used above the iliac vessels, especially in females or thin males without large psoas muscles. The semi-rigid ureteroscope can reach beyond the pelvic brim with some degree of bending, possible because it is constructed with fiberoptic bundles instead of the classic rod–lens system. However, the endoscopic surgeon needs to become familiar with the tactile feedback in order to avoid iatrogenic injury or scope damage.

Distal ureteroscopy is most commonly performed for the treatment of ureteral stones since ureteroscopic management of distal stones, regardless of stone size, yields better stone-free rates than shock-wave lithotripsy (SWL) [1]. Other indications include endoureterotomy for ureteral stricture, evaluation of filling defects on intravenous or retrograde pyelography, biopsy or ablation of upper tract transitional cell carcinoma (TCC), surveillance of previously treated TCC, and in combination with flexible ureteroscopy, for the evaluation of hematuria and/or positive cytology with normal cystoscopy.

Ureteroscopy is expanding its frontiers and now is becoming more widely accepted as first-line therapy after failed conservative management of urolithiasis in prepubertal children and pregnancy, urolithiasis in patients with urinary diversions, morbid obesity, and renal ectopia or fusion abnormalities [2–9].

Preoperative evaluation and patient positioning

Preoperative evaluation requires careful history taking pertinent to the urologic disease being treated, but also aimed at identifying pathology that may affect or compromise the smooth flow of surgery. Prior urologic procedures, pelvic radiation, or orthopedic conditions that may preclude adequate patient positioning need to be elicited.

An explanation of the procedure with its goals and potential complications, and the possibility of placing

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an indwelling ureteral stent are discussed in the informed consent. The majority of ureteroscopies can be performed as outpatient procedures.

Of all preoperative laboratory studies, a negative urine culture is of paramount importance. It has been shown that for ureteroscopic lithotripsy with the holmium laser, bleeding diathesis does not need to be corrected; for all other ureteroscopic procedures, a normal coagulation profile is mandatory [10]. If the coagulopathy can be safely reverted, it is probably justified to do so since rigid ureteroscopic access may potentially require the use of balloon or ureteral dilators that even when used correctly can lead to trauma with ensuing bleeding.

The American Urological Association recommends 24-h antimicrobial prophylaxis for all upper tract instrumentation. Antimicrobials of choice are fluoroquinolones or trimethoprim–sulfamethoxazole (TMP–SMX). Alternative antibiotics include an aminoglycoside with or without ampicillin, a first- or second-generation cephalosporin or amoxicillin/clavulanate. In patients with renal insufficiency, aminoglycosides can be substituted for aztreonam [11].

After regional or general anesthesia, the patient is placed in the dorsal lithotomy or modified dorsal lithotomy position, depending on the surgeon's preference. In the modified position, the leg that is ipsilateral to the ureter being explored is lowered and slightly abducted as it is believed that this position aligns the affected ureter with the rigid instrument.

Video monitoring is routinely used because it is more ergonomic to the operating surgeon and facilitates the teaching of trainees. It also enables documentation either in the form of still pictures or movies that can be incorporated into the patient's electronic records.

Equipment for ureteroscopic access

Ideally, ureteroscopy takes place in a lead-shielded endourology-dedicated operating room, which consists of a fixed urology-specific endoscopy table with fluoroscopic capabilities and at least two monitors that receive fluoroscopic and endoscopic feed. The monitors, attached to ceiling mounted booms, are placed in front of the surgeon who stands in between the patient's legs. Fluoroscopy is controlled by the surgeon by activation of a foot pedal.

Operating room personnel must wear adequate protective gear, including lead aprons and thyroid shields. Dosimetry badges are needed to record individual exposure to radiation. Lead glasses are especially recommended for endoscopic surgeons due to their proximity to the radiation source and chronic exposure.

Basic equipment for all distal ureteroscopies includes a rigid or a flexible cystoscope, an open-ended ureteral catheter, guidewire(s), and contrast. Lenses of 12º and 70º, and a cystoscopic sheath greater than 17F to accommodate a ureteral catheter are needed if rigid cystoscopy is contemplated.

Guidewires

Guidewires are key to a successful endoscopic procedure because they allow constant access into the upper tract. Access is especially important during difficult cases because it enables the surgeon to negotiate a troublesome spot either to find back the ureter and continue with the ureteroscopy or to deploy a stent and return at a later date. Wires are also used to monorail ureteral dilators, sheaths, and flexible endoscopes into the upper tracts, and as such are made of different materials that enhance the purpose for which they were designed.

In general, guidewires have two components: an inner core that determines the stiffness of the guidewire shaft and the flexibility of the tip, and an outer coating that determines guidewire lubricity. Stainless steel core wires can be made to have different core stiffness (i.e. floppy tip vs super stiff) and can permanently kink if manipulated inappropriately. In contrast, the more expensive nitinol wires consist of a nitinol core with a polyurethane jacket and a hydrophilic polymer coating. Nitinol does not kink. The hydrophilic coating of the nitinol-type wires must be kept moist, because it becomes tacky if it dries out [12].

Polytetrafluoroethylene (PTFE)-coated, stainless steel wires with a floppy tip are probably the most common and least expensive wires. Hydrophilic (nitinol) wires with straight or angled tips absorb water to become very slippery and atraumatic, and are purposely designed to gain upper tract access in the setting of an obstructing stone or ureteral kink or obstruction. However, due to their slippery nature they are not suited to instruments being delivered over them and need to be exchanged once upper tract access is gained. Super-stiff wires are more kink resistant than the other types, and are therefore best used for proximal deployment of ureteral dilators (balloon, sheaths, or coaxial) and to "straighten"' a tortuous ureter. Hybrid or combination wires combine a flexible hydrophilic-coated floppy tip, which facilitates access, with a kink-resistant core that allows for working instruments to be delivered over them, thus avoiding the use of multiple other wires.

Ureteral dilators

Ureteral orifice dilation is seldom necessary when using the newer and smaller semirigid ureteroscopes. However, on occasions it is necessary to dilate the ureteral orifice or a more proximal ureteral stricture using either a balloon or a coaxial ureteral dilator or the obturator of an access sheath.

Balloon dilators have a deflated shaft diameter of 5F, balloon lengths between 4 and 10 cm, and an inflated profile of 12–30F. They are placed over a super-stiff or hybrid wire straddling the area of interest and inflated up to 20 atm of pressure with diluted contrast with a specially designed syringe. They produce radial dilation which is thought to result in less ureteral trauma than the shearing forces of ureteral dilators.

Polyethylene or PTFE coaxial dilators range in size from 6F to 18F and are sequentially passed over a wire under fluoroscopic vision across the narrow segment.

The ureteral access sheath is not used for semi-rigid ureteroscopy; however, if the surgeon anticipates a need for inspection of the more proximal ureter with a flexible ureteroscope and the need for an access sheath, the obturator with its tapered tip (approximate shaft diameter of 11–13F) can be used to softly dilate the stricture.

Irrigation systems

Irrigation under pressure, always using normal saline at body temperature, is required to actively create a space to work in. Normal saline is the irrigant of choice because there is always a risk of absorption from pyelolymphatic or pyelovenous backflow or from ureteral perforation. Irrigation with glycine (or water) is no longer needed as since the advent of the holmium laser, which allows for fulguration and ablation of tissue, electrosurgery has been made obsolete.

Different irrigation systems have been described, the most common of which uses a pressure bag. A Level 1 System (Level NORMOFLO Irrigation Warming Set, Smiths Medical ASD, Rockland, MA, USA) delivers precision control of the irrigant and warms it to body temperature. Manually inflated reusable pressure bags can also be used. Another option is a control pump syringe or a hand-held bulb pump attached to gravity irrigation. In this case, the operating surgeon or their assistant provides pressure irrigation during critical parts of the procedure, with the obvious disadvantage that constant visualization is not maintained. A hands-free irrigation system that is activated by a foot pedal and another that requires a hydraulic pump have also been used [2, 13].

Endoscopes and video equipment

Semi-rigid ureteroscopes contain fiberoptic bundles instead of the classic rod –lens system, which allow a small amount of axial bend. They have a tapered profile, smallest at the tip (6–8.5F) and progressively widening to a larger shaft by the eyepiece (7.5–11.2F).

Semi-rigid ureteroscopes are preferred over their flexible counterparts whenever possible, and especially in the distal ureter because of their larger working channels, faster irrigation, better and bigger image quality, and durability. Moreover, flexible ureteroscopes are difficult to use in the distal ureter because of their lack of "purchase" of this ureteral segment.

In 2006 the world's first semi-rigid video ureteroscope was introduced. The image is captured by a charged coupled device (CCD) chip at the endoscope's distal tip and carried by wire to the control box. This control box acts both as the light and camera boxes of the standard set-up. This design obviates the need to attach a camera to the eyepiece, resulting in an easier set-up and a lighter hand piece. There is no need for a separate camera, camera cord, light box, and light cord. When compared to standard semi-rigid ureteroscopes, the image of videoendoscopes is larger and without the honeycomb effect due to the absence of image-carrying fiberoptic bundles.

Step-by-step distal ureteroscopic access

Cystoscopy and guidewire placement

Flexible or rigid cystoscopy can be used for a systematic assessment of the bladder mucosa to rule out bladder pathology and for initial guidewire placement in the ureter. Rigid (rod–lens) cystoscopes offer better image quality and irrigation capabilities, and are easier to operate than standard flexible equipment. However, in patients with prominent prostatic median lobes or high-riding bladder necks, visualization of the ureteral orifice may prove difficult with a rigid cystoscope and may require the use of a 70° lens and an Albarran deflector. Alternatively, a flexible endoscope can be used.

Ureteroscopy usually begins with a retrograde pyelogram to determine the upper tract ("road map") ahead. However, if the semi-rigid ureteroscopy is performed for a distal stone and there is no need for ureteral dilation, we prefer to insert a 0.035-inch hybrid wire up into the ureter until it is coiled in the kidney, obviating the need for a pyelogram out of concern that it may produce proximal stone migration.

Proper guidewire position is always confirmed fluoroscopically. This safety wire should be kept in place for the duration of the case as it will prove useful to deploy a stent in the event of a perforation or to regain access into the more proximal collecting system in the setting of bleeding. If there are doubts as to the correct placement of the wire, or if the wire does not progress proximally, it is exchanged for a straight open-ended 5F ureteral catheter through which a gentle (low-pressure) retrograde pyelogram is performed with diluted contrast. If the wire is bouncing against an obstruction or stone and not progressing forward, a hydrophilic wire, straight or angled tip, is deployed through the open-ended stent, used as a backing, to negotiate the wire past the restriction. In the event that this fails, the open-ended stent can be exchanged for an angled stent, which in combination with a hydrophilic angled wire exponentially increase the angles of attack of the tip of the wire against the obstructing stone.

If the retrograde pyelogram shows extravasation, the ureteroscopy should be stopped and a stent deployed. If the extravasation occurs prior to having a safety wire in the kidney, either because it could not be manipulated into the intrarenal collecting system or because access was lost during the procedure, and proximal access cannot be regained expeditiously, percutaneous nephrostomy tube drainage is indicated to avoid ongoing extravasation and to relieve the obstruction.

Ureteroscope insertion

After proper guidewire placement, the semi-rigid ureteroscope is advanced alongside the wire into the bladder. It is useful to find the guidewire at the bladder neck and follow it to the ureteral orifice since the field of view is much smaller than with the cystoscope (see Video 46.1). The orifice is usually tented up by the wire. The tip of the scope is then positioned "opposite" the wire to gain access (see Video 46.2). Positioning the scope on the wrong side of the wire will preclude ureteral entry.

The beveled tip design of modern semi-rigid ureteroscopes allows for relatively easy access across the ureteral orifice. The endoscope is then advanced only when the instrument slides freely and there is a clear field of view. If resistance to the passage of the scope occurs, the scope is pulled back, rotated, and reintroduced (see Video 46.3). If the endoscopic image is not clear, the scope is slightly withdrawn as it may be against the ureteral mucosa.

Most often semi-rigid ureteroscopy does not require orificial dilation; however, when needed it is accomplished with a balloon dilator, coaxial ureteral dilators, or an access sheath. In 1991 Garvin and Clayman showed no clinical consequences from balloon dilation of the ureteral orifice to 24F [14]. Currently, with the newer and smaller fiberoptic ureteroscopes, ureteral dilation is probably not needed beyond 12–15F.

Ureteral dilation

If the surgeon anticipates during cystoscopy/retrograde pyelography that the ureteral orifice or ureter needs to be dilated, a hybrid (combined) or super-stiff wire is deployed and balloon dilation under endoscopic and fluoroscopic vision is performed (see Videos 36.4–36.7). The balloon is fed over the wire and through the cystoscope, positioned straddling the narrow segment, and then slowly inflated to visualize the contour of the stricture as the balloon "waists" around it before it becomes fully inflated (Figure 36.1; see Video 36.4) Alternatively, coaxial ureteral dilators can be used over a wire under fluoroscopic vision.

Ureteral access in patients with altered anatomy

Ureteral reimplant and ureteral J-hooking

Occasionally the trigonal anatomy is distorted and the ureteral orifices are not orthotopically located, as in patients with previous ureteral reimplantation. The Glenn-Anderson technique advances the ureteral orifice distal to its native position, while the Cohen technique crosses the orifice to the opposite trigone. The Cohen technique is perhaps the most popular today; however, it has the potential disadvantage of hindering future retrograde ureteroscopic access to the kidney [15].

Wallis *et al*. described a technique that permits catheterization and ureteroscopy after a Cohen reimplantation. After cystoscopic access and visualization of the ureteral neomeatus, an angled-tip ureteral catheter is inserted via the cystoscope and aimed at the ureteral orifice. Grasping the catheter at its hub allows 360º rotation of the tip. Next, a hydrophillic angled-tip guidewire with a torque device attached is passed through the catheter and directed into the orifice. The torque device also permits 360º rotation of the guidewire tip. The combination of the curved catheter and angled guidewire permits eventual cannulation of the reimplanted ureter. The wire is then negotiated up the ureter. A catheter is passed over the wire into the ureter and a retrograde pyelography is performed, confirming proper positioning. A super-stiff wire is then deployed which may straighten the ureter to allow rigid or flexible ureteroscopy using standard techniques [16].

A similar technique of cannulation with a hydrophillic wire, later exchanged for a super-stiff wire to rectify the ureteral alignment and facilitate ureteroscopy, can be employed to deal with J-hooking of distal ureters, transplant ureters, or ureters reimplanted into a psoas hitch or a Boari flap. A tortuous, redundant ureter can similarly be straightened to facilitate flexible ureteroscopy. However, care needs to be exercised to avoid excessive torquing of the semi-rigid ureteroscope when advancing it beyond surgically altered anatomy, and a low threshold to switch to a flexible endoscope should exist.

If ureteroscopy fails due to surgically altered anatomy of the distal ureter, a percutaneous approach for antegrade endoscopy may be required.

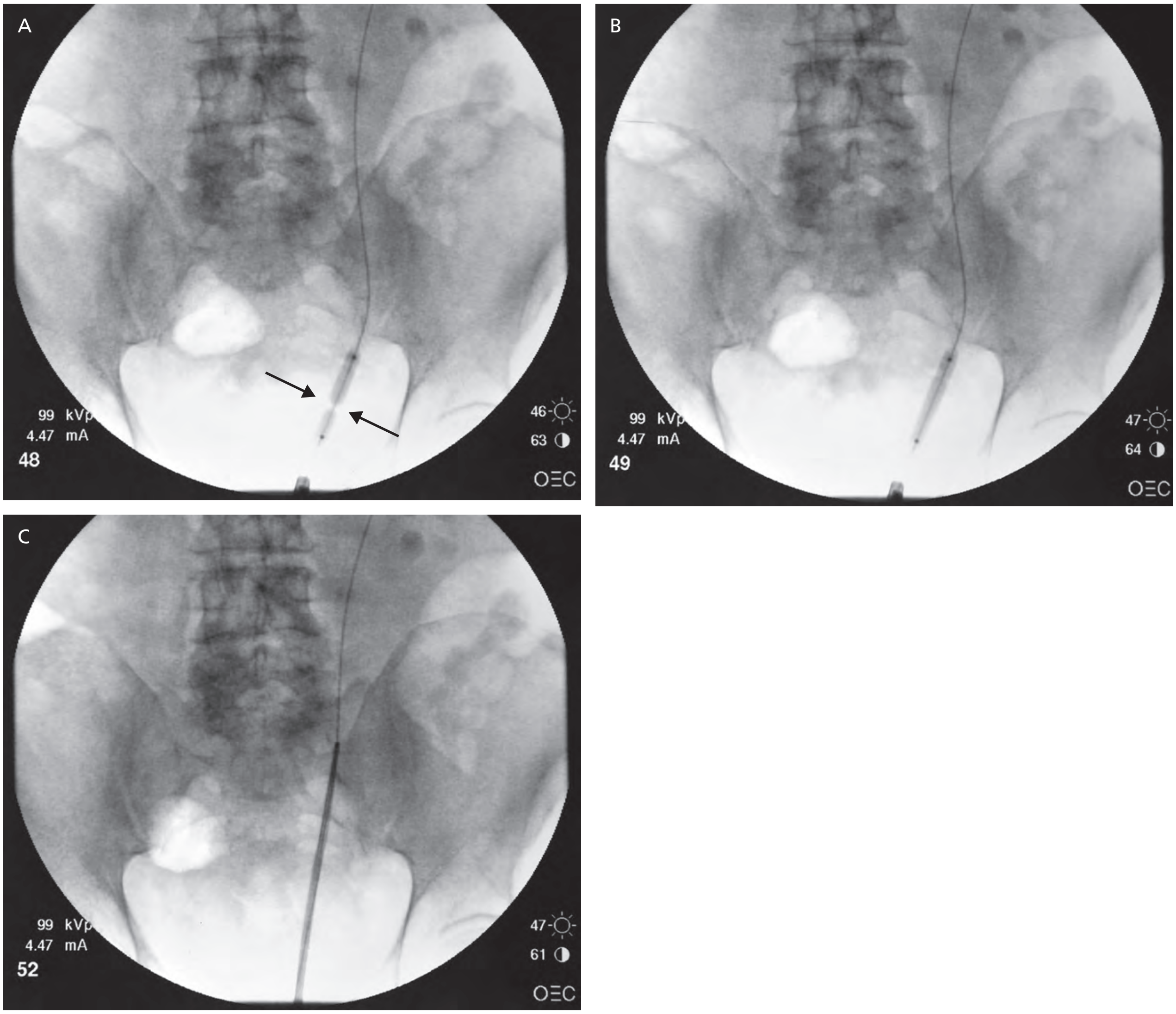

Figure 36.1 (A) Balloon is slowly inflated with dilute contrast solution, and a “waist” forms around the stricture (arrows). (B) Fully inflated balloon. (C) Easy ureteroscopic access beyond stricture.

Urinary diversion

Cannulation of ureters implanted into urinary diversions follows the same previously described technique. However, in patients with Studer or Hemi Kock neobladders, upper tract access with a semi-rigid ureteroscope is usually not feasible due to the 3D spatial relationship between the ureteral neomeatus and the bladder neck. Continent catheterizable diversions are probably best approached with a flexible cystoscope to avoid injury to the continent mechanism through excessive torquing of a rigid device against it. Ileal conduit diversions usually allow cannulation of the anastomoses with a rigid cystoscope unless an excessively long bowel segment was used for their construction.

Finding the ureteroenteric anastomoses and obtaining ureteral access is probably the most challenging part of the procedure. Knowledge of the type of diversion and in the case of a neobladder, whether it has an afferent limb, will greatly improve the ability of the surgeon to find the anastomoses. However, it may still be difficult to find the reimplanted ureters due to the presence of mucus, occasionally large capacity of the diversion, lack of landmarks, and a constantly moving target due to peristalsis.

A combined antegrade and retrograde approach has been described to facilitate retrograde access to the ureteroenteric anastomosis and ureter in diverted patients. A previously placed small-bore percutaneous nephroureteral stent with its distal tip in the urinary diversion is exchanged for a super-stiff wire and cystoscopically retrieved from the diversion, thus providing through-and-through access, which enables rapid and easier retrograde identification of the anastomosis and segment of interest in the upper tract. Furthermore, this approach allows the use of larger semi-rigid or flexible endoscopes in conjunction with more efficient fragmentation devices, resulting in enhanced vision from better irrigation [17].

Ureterocele

A single-system ureterocele usually manifests in adults. It is almost always intravesical and occupies the proper trigonal position. The degree of obstruction is probably not significant in most adult cases; however, patients may present with an obstructing ureterovesical junction (UVJ) stone. Since most single-system ureteroceles have pinpoint orifices, access may require dilation or incision of the ureterocele before ureteroscopic access, usually through a transverse incision as close to the bladder floor as possible, through the full thickness of the ureterocele wall. An incision low on the ureterocele lessens the chance of postoperative reflux [18].

Stone impaction at the ureterovesical junction

Occasionally, a stone is found impacted at the ureteral orifice, which becomes edematous. In this scenario, and after deployment of a safety wire, the stone is gently pushed back with the tip of the ureteroscope into the dilated intramural ureter, or laser fragmentation is begun from the bladder side to dislodge the stone and enter the ureter. On occasions, a 12 o'clock holmium laser ureterotomy, incising the ureteral orifice over the stone, is required.

Ureteral trauma

The ureteral segments more prone to injury during ureteroscopy are at the UPJ and UVJ, where the muscular backing of the ureter is thinnest, and at the pelvic brim due to the angulation of the ureter over the psoas muscle [19]. In special situations, where the ureteral orifice or mucosa are edematous and friable secondary to unsuccessful traumatic wire deployments or stone impaction, or in the setting of an ureteral false passage, access requires driving the scope to the traumatized area and deploying a wire under direct ureteroscopic vision. If there is significant ureteral trauma, multiple fluoroscopic attempts with catheters and wires may traumatize the area further and ultimately lead to failure to deploy a wire in the kidney.

For this reason, if the patient has a previously placed indwelling ureteral stent, and especially if there is periureteral orifice edema, we prefer to deploy the safety wire alongside the stent prior to removing it. This maneuver facilitates the visualization of the orifice and may avoid an intramural ureter false passage.

Conclusions

A thorough knowledge of the endoscopic equipment and disposable instrumentation is mandatory for a successful ureteroscopy. Atraumatic guidewire access maintained throughout the duration of the case allows for smooth navigation in difficult cases and provides an exit strategy that allows return at a later date. The constant evolution of endoscopic equipment and instruments is enabling the realization of increasingly more challenging procedures.

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CHAPTER 37

Access to the Ureter: Flexible Ureteroscopy

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Introduction

Retrograde flexible ureteroscopy (URS) is a widely utilized technique for evaluation and treatment of upper urinary tract pathology, both benign and malignant. Technologic improvements (e.g. smaller caliber ureteroscopes, greater active deflection) have expanded the role of flexible URS for the management of these processes, including urolithiasis, ureteral stricture disease, and upper tract urothelial or transitional cell carcinoma (TCC). Obtaining ureteral access for flexible URS is typically straightforward, but can be challenging depending on anatomic and disease factors.

In this chapter, we review the preoperative evaluation of patients undergoing flexible URS, preparation of the operating room, and techniques for standard and difficult access. We also review the role and technique for ureteral access sheath (UAS) placement to enable rapid and safe re-entry into the ureter, particularly in the management of stone disease.

Preoperative evaluation

A thorough history and physical examination should be performed preoperatively. History details that may illuminate an increased risk of difficult access should be elicited. Advance knowledge of these risk factors allows for preoperative planning as well as appropriate counseling of patients regarding risks and the possibility of failed access.

Specific aspects of the past medical history should be emphasized. History of benign prostatic hyperplasia and/or bladder outlet obstruction should be elicited. A large occlusive prostate may impede bladder access and, if friable, may impair visualization secondary to bleeding. A large intravesical median lobe may obscure visualization of one or both ureteral orifices. Chronic bladder outlet obstruction may also cause bladder trabeculations or diverticula, which may distort intravesical anatomy and hinder the identification of the orifices. A history of pelvic or retroperitoneal radiation, or of trauma, may increase the likelihood of scar tissue formation, leading to tissue or anatomic distortion. Abdominal aortic aneurysms should be noted as they may cause extrinsic compression of the ureter and/or deviation. Patients with retroperitoneal fibrosis, which may be secondary to numerous processes (e.g. trauma, medication-related, idiopathic), may also have narrowing of the ureter.

Surgical history pertaining to the urinary tract should be reviewed. Prior open or endoscopic interventions may increase the risk of ureteral stricture disease and thus hinder access. Prior surgery may alter anatomy, including ureteral reimplantation with neoureterocystotomy. Reimplantation may also convey risk of vesicoureteral anastomotic stricture or reflux. Review of prior operative reports may guide access regarding location of the new orifice. Prior urinary diversion surgery similarly requires ureteral reimplantation, which can make a retrograde approach technically challenging and

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has a potential risk of ureterointestinal anastomotic stricture. Finally, prior abdominopelvic (e.g. colorectal surgery, hysterectomy/salpingo-oophorectomy) or retroperitoneal surgery (e.g. abdominal aortic aneurysm repair) can lead to stricture disease from injury to or devascularization of the ureter.

Other pertinent details of the patient history include use of anticoagulants or antiplatelet agents. Often these agents can be stopped in consultation with a cardiologist or internist; however, in certain instances patients cannot safely stop these medications and the procedure should be performed as atraumatically as possible. Ureteral dilation techniques should be avoided when operating on patients who are actively anticoagulated. If there is difficulty with access to the ureter, a ureteral stent should be placed to allow for passive dilation prior to definitive treatment. There is evidence that ureteroscopic interventions in patients taking these agents are safe, particularly in the management of stone disease [1].

Another important detail of the history is whether a patient demonstrates signs or symptoms of urinary tract infection, or risk factors for colonization of the urinary tract. Patients should be treated to clear an acute infection prior to surgery. Those with colonization should be placed on culture-specific antibiotics prior to surgery to minimize risk of urosepsis with instrumentation.

Informed consent is necessary prior to proceeding to the operating room. Risks and benefits of the proposed surgery should be discussed with the patient preoperatively; these include but are not limited to bleeding, infection, injury to the kidney, ureter, and adjacent structures, and ureteral stricture. Patients should be informed of the risk of failed access and the possible need for ureteral stent placement with abortion of the procedure and/or percutaneous nephrostomy tube placement. The more thoroughly patients are counseled preoperatively, the greater trust will persist postoperatively if these situations occur, and subsequent counseling of the patient will be facilitated.

Preparation of the operating room

Prior to flexible URS, the operating room staff should confirm that all potential instruments and disposable equipment are available, and the surgeon should confirm that this equipment is correct (Table 37.1). The steps of the procedure should be anticipated and the scrub table organized to ensure a smooth succession of events. Additional equipment for difficult access cases may also be required at the discretion of the surgeon (Table 37.1). If access fails, the patient may require a percutaneous approach or nephrostomy tube, which can be placed by the urologist or interventional radiologist.

Table 37.1 Equipment for standard and difficult ureteral access for flexible ureteroscopy.

Standard access
Rigid cystoscope (30 and 70° lens) with light cord, camera, and irrigation fluid (Albarran bridge if desired)
Nitinol guidewires: 0.035 or 0.038 inch [hybrid guidewire if desired – polytetrafluoroethylene (PTFE):nitinol with hydrophilic tip]; at least two wires (working and safety)
Dual-lumen or coaxial catheter
Contrast medium (50:50 ratio with saline) for retrograde pyelography with syringe for injection
If retrograde pyelogram needed before access to upper tract performed → 5F or 6F open-ended catheter or cone-tip catheter
Ureteral access sheath at the discretion of the surgeon
Flexible ureteroscope (tested to ensure clear lens and adequate deflection)
Ureteral stent (double-J or pigtail) with different calibers and lengths (or multi-length)
Difficult access
Flexible cystoscope
Semi-rigid ureteroscope
Angiographic catheters with an angled tip
Balloon dilators
Serial dilators
Angled-tip and straight hydrophilic guidewires (with torque device if needed)
Various size wires (e.g. 0.025 inch)

Balloon dilators are useful for accessing anatomically tight or strictured segments of ureter. Dimensions of balloon dilators vary by manufacturer; we typically use 4-, 6- or 10-cm dilators with 12–15F balloons inflated to 12 atm. Dimensions of available standard ureteral balloon dilators include balloon lengths of 4–10 cm, inflated balloon diameters of 12–18F (4–6 mm), and dilation pressures up to 30 atm.

Fluoroscopy (C-arm or table) is required to guide positioning of wires, catheters, and ureteral access sheaths, and to enable retrograde pyelography. Placement of the flexible ureteroscope can be performed with fluoroscopic guidance over the working guidewire up to the level of disease, e.g. stone or stricture. Fluoroscopy is also useful for identification of radio-opaque stones and following the fragmentation of a stone during laser lithotripsy. The surgeon should confirm that fluoroscopy is correctly positioned and can be easily manipulated prior to surgery.

Standard retrograde access for flexible ureteroscopy

Depending on institutional protocol, the surgical site (i.e. side for ureteroscopy) should be marked by the operating surgeon.

The type of anesthesia will depend on a detailed conversation between the anesthesiologist, surgeon, and patient, and may be influenced by numerous factors (e.g. cardiopulmonary status of the patient, need for apnea during the procedure, patient preference).

The patient is positioned in the dorsal lithotomy position, and prepped and draped in standard sterile fashion. A single dose of prophylactic antibiotic is administered prior to the procedure if the preoperative urine culture is negative. If the patient has a positive preoperative urine culture, they should be treated with a full course of culture-specific antibiotics prior to intervention. Sequential compression devices should be placed on the patient's lower extremities prior to induction of anesthesia. Alternatively, deep venous thrombosis prophylaxis can be given with subcutaneous heparin or low molecular weight heparin.

The bladder is initially entered with a rigid cystoscope. After cystoscopic evaluation of the bladder, the relevant ureteral orifice is identified and cannulated with a guidewire. The guidewire may advance through the end of the rigid cystoscope directly into the orifice, or a 5F open-ended catheter may be required to provide the correct angle for intubation of the orifice. Keeping the camera stationary, the scope can be rotated to change the angle at which the wire advances. When advancing the wire into the orifice, it is important to ensure the end of the cystoscope sits directly at the orifice to prevent buckling or curling of the wire in the bladder. We prefer to use a 0.035 or 0.038 inch x 150 cm hybrid guidewire because its flexible, hydrophilic tip minimizes trauma to the upper urinary tract, it allows easy manipulation around upper urinary tract stones and obstruction, it is kink-resistant, and it has sufficient rigidity to act as a working wire. The wire is advanced gently under fluoroscopic guidance into the kidney (Figure 37.1), minimizing trauma to the collecting system which can lead to mucosal bleeding and obscure visualization. This is particularly important when URS is being performed for evaluation of upper tract TCC as wire trauma may confound evaluation of TCC or carcinoma *in situ*. Also, patients who are anticoagulated or have bleeding diathesis may have significant bleeding from wire trauma, thus extra caution is necessary in these patients.

If the wire does not advance easily, a retrograde pyelogram should be performed over an open-ended catheter (or with the use of a dual-lumen catheter placed over the initial guidewire) to delineate the ureteral anatomy (e.g. evaluate for presence of ureteral tortuosity or obstruction). Methods of addressing an inability to advance the initial wire are discussed below.

With the first wire in the correct position, the bladder is emptied through the cystoscope (side port or sheath) to maximize the likelihood of successful passage of a catheter and/or ureteroscope through the intramural ureter. At this time, we recommend placement of a

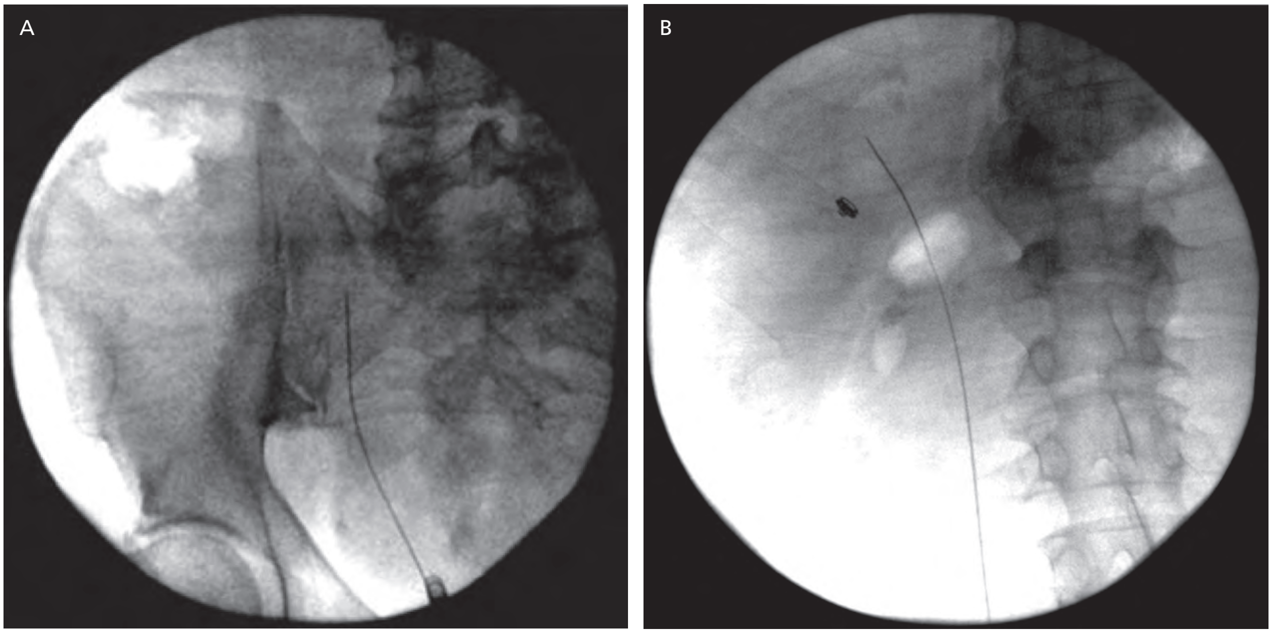

Figure 37.1 Guidewire advanced to (A) mid ureter and (B) level of kidney.

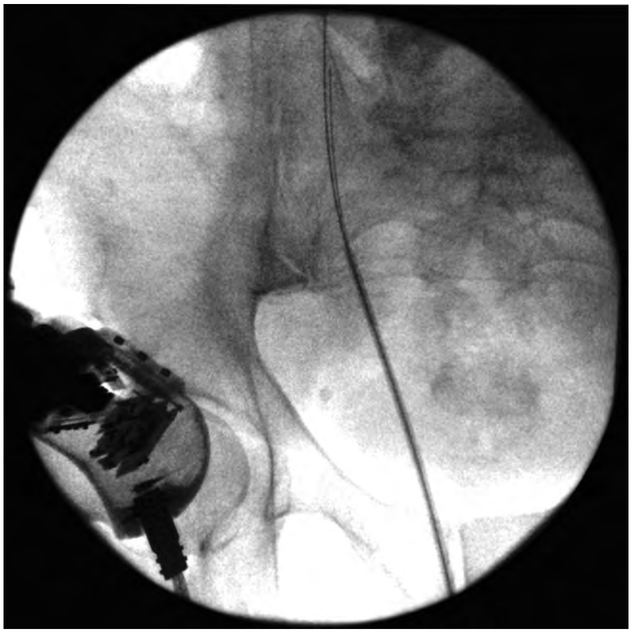

Figure 37.2 Dual lumen catheter with two wires advanced.

second wire as a safety wire. A safety wire allows for ureteral stent placement at any time should there be iatrogenic injury or an inability to proceed. It will also prevent loss of access to the upper urinary tract during the surgery. A dual-lumen or coaxial catheter can be placed over the initial wire into the distal ureter under fluoroscopic guidance and the second wire is advanced alongside the first wire to the renal pelvis (Figure 37.2). A retrograde pyelogram can be performed through the dual-lumen catheter prior to second wire placement if it has not been performed earlier. Alternatively, a second wire can also be placed under direct vision through the cystoscope adjacent to the first wire. The benefit of using a dual-lumen 10F catheter or 8/10F coaxial catheter is that these gently dilate the distal ureter, allowing for easier passage of the flexible ureteroscope.

After the second wire is placed, the dual-lumen catheter is removed and one wire is secured to the drape as a safety wire. The safety wire should be secured away from the immediate surgical field to minimize risk of dislodgement. At this time, the flexible ureteroscope is placed over the working wire and advanced to the level of interest under fluoroscopic guidance.

Difficult retrograde access for flexible ureteroscopy

Certain situations can confound efforts to obtain ureteral access. Below we discuss methods of troubleshooting these scenarios.

Ureteral orifice(s) cannot be visualized

There are various reasons why ureteral orifices may not be readily visible on cystoscopic evaluation: distorted anatomy (e.g. bladder trabeculations, mucosal edema, neoplasm), obscured anatomy (e.g. intravesical median lobe), congenital anomalies (e.g. ureteral ectopia), or prior surgery (e.g. ureteral reimplantation, resection). If there is anatomic distortion, an ampule of indigo carmine or methylene blue can be administered intravenously and efflux of dye can be sought. It is important that patients are well hydrated, have adequate renal function, and do not have significant obstruction of the ipsilateral kidney to ensure the dye is rapidly excreted. Intravenous furosemide can be concomitantly administered to expedite excretion from the kidneys. If there is obscured anatomy from a large median lobe, a rigid cystoscope with a 70° lens may enable identification of the orifice. A flexible cystoscope can also be utilized to identify the orifice beneath the lobe and in patients with a very high riding bladder neck, which prohibits bladder access with a rigid scope. Accessing the orifices with flexible cystoscopy can be technically challenging as irrigant flow and visibility are inferior to those with a rigid scope, and achieving the correct angle for access of the orifice may be difficult. Additionally, the use of an Albarran deflecting bridge or an angled-tip angiographic catheter (e.g. 5F Berenstein catheter) can help deflect guidewires into a ureteral orifice that is at an acute angle or distorted secondary to bladder and prostate anatomy.

If the orifices cannot be found, there should be consideration of congenital anomalies or prior surgical history that may have altered their position. Preoperative imaging can be helpful in delineating upper tract anatomy, including ectopic ureters; urographic imaging is particularly helpful. Clinical history may reveal the possibility of variant or altered anatomy, e.g. history of vesicoureteral reflux disease, incontinence, or chronic pyelonephritis. Review of prior operative reports may provide guidance regarding location of ureteral orifices after ureteral reimplantation.

Guidewire will not advance through the ureteral orifice

The tip of the cystoscope should be placed immediately at the ureteral orifice to prevent kinking of the wire. A 5F open-ended catheter can be placed through the cystoscope and used as a guide and/or support for the wire, creating the desired angle for access and preventing kinking. An angiographic catheter can also be used for this purpose. Use of an open-ended catheter also allows for retrograde pyelography; the catheter can be placed at the orifice and contrast injected to determine if there is patency of the orifice and/or distal ureter.

With the open-ended catheter at the orifice, either a straight or angled-tip guidewire (nitinol or hydrophilic) can be gently advanced and manipulated. If there is concern for a stricture at the orifice or an impacted stone, a rigid ureteroscope can be used to directly access the orifice and wire placement under vision can be attempted. If there is an impacted stone, it can be treated to expose the proximal lumen and enable wire placement; however, without a safety wire this should be done with care. If wire access cannot be achieved and there is clinically significant obstruction, the procedure should be aborted and a percutaneous nephrostomy tube placement should be performed.

Guidewire will not advance through the ureter to the kidney

If the wire has successfully accessed the ureteral orifice but will not advance past a level of ureter, an open-ended catheter should be placed over the wire and a retrograde pyelogram performed to ensure there is no stricture, ureteral injury/false passage, obstructing lesion or stone, or severe tortuosity/J-hooking. This can also be performed with a dual-lumen catheter which can be advanced over the guidewire that has already been placed. If the open-ended catheter will not easily advance over the wire, it is possible that the wire has been placed submucosally, and it should be withdrawn and replaced in the true lumen. If there is a transition point for obstruction or severe tortuosity, the open-ended catheter can be placed to that level to prevent buckling of the wire as it is advanced. An angled-tip hydrophilic guidewire can be useful if there is a severe angle to negotiate. Surgeon experience is critical to understanding how much pressure can be safely applied while advancing the wire. If there is obstruction and concern for a pinpoint stricture, an experienced surgeon may place the ureteroscope over the wire to the level of interest and then attempt to advance the wire under vision. Also, if there is a severely impacted stone and inability to obtain proximal access with a wire, an experienced surgeon can attempt to treat the stone with caution to expose the proximal ureter and enable safety wire placement. Importantly, without a safety wire in place these maneuvers can worsen obstruction, cause damage to the ureter without an option for immediate stent placement, and necessitate percutaneous nephrostomy tube placement.

If a guidewire cannot traverse the level of obstruction, the procedure should be aborted and nephrostomy tube placement should be considered. If access is achieved but traumatically, a retrograde pyelogram should be performed and ureteral stent placement with deferral of the procedure should be considered if there is extravasation.

Initial guidewire placement was successful, but a coaxial/dual-lumen catheter or ureteroscope will not advance through the ureteral orifice

First ensure that the bladder is empty; it is not uncommon to neglect to empty the bladder before removing the cystoscope. Careful twisting and advancement of the dual-lumen catheter, which has a tapered tip, can often enable access into the distal ureter. While advancing the catheter over a wire, it is important that the wire remains stationary (secured by the surgeon or an assistant) to allow the catheter to advance without buckling. Inability to advance the catheter may indicate anatomic narrowing or stricture at the ureteral orifice. This necessitates a decision whether a ureteral stent should be placed and the procedure deferred for 5–7 days for passive dilation of the ureter, or whether ureteral dilation should be performed. Our algorithm usually begins with retrograde pyelography with a dual-lumen catheter. If multiple areas of the ureter appear narrow in addition to the ureteral orifice, we place a ureteral stent and return to the operating room in approximately 1 week. If the ureteral orifice or intramural tunnel appears to be discretely narrow or strictured, several dilation techniques are available.

Ureteral balloon dilation can be performed by advancing a balloon dilator over the wire and ensuring the radio-opaque markers span the orifice (Figure 37.3). The balloon is filled with contrast and held at 12 $\mathrm{cmH_2O}$ for approximately 1 min. The balloon is then deflated and removed, and the dual lumen catheter is advanced over the wire to allow for passage of the second working guidewire (if not already placed). The ideal balloon dilator for this region is 4 cm x 12F, which minimizes trauma to the ureter and the risk of extravasation, and has not been shown to cause ureteral structuring [2]. Active dilation can also be performed with serial dilators (e.g. Nottingham dilators). Finally, dilation can be performed under direct vision with a semi-rigid ureteroscope.

While dilation may enable access to the ureter, it can be traumatic and cause edema and/or urinary extravasation; thus, it is important to ensure a ureteral stent is placed at the end of the case if dilation is performed. When treating a stone, it is important to be aware if a distal stricture is present as residual fragments may not pass after stent removal, and risk of an obstructing fragment or steinstrasse may be increased. A ureteral stricture should be ideally treated prior to the treatment of a more proximal stone, and allowed to heal prior to lithotripsy. Concomitant treatment can increase the risk of submucosal stones or stone granuloma formation, which can lead to stricture disease.

If a dual-lumen catheter will not advance despite balloon dilation, or if balloon dilation is contraindicated

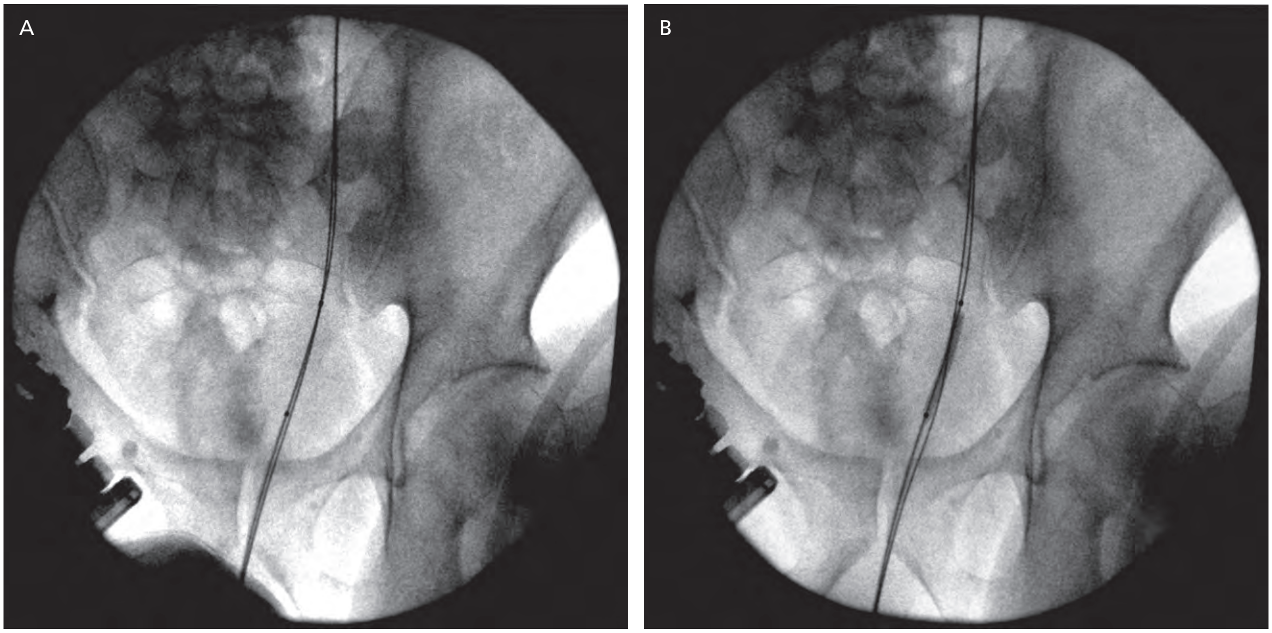

Figure 37.3 Balloon dilator. (A) 4 cm × 12F ureteral balloon dilator positioned in the intramural tunnel. –(B) Balloon expanded to dilate distal ureter/intramural tunnel.

(e.g. bleeding diathesis), a ureteral stent should be placed to allow passive dilation of an anatomically tight ureteral orifice and healing of a dilated stricture, and/or to relieve acute obstruction. Without a safety wire it is typically not recommended to proceed with ureteroscopy when an intervention is anticipated, except in the hands of experienced endourologists. With the newer generation flexible ureteroscopes, ureteroscopy has been demonstrated to be safe without the use of a guidewire ("wireless") [3].

If a wire has passed but even a stent will not advance through the orifice, a small open-ended catheter can be advanced to the kidney and secured to the Foley catheter; this can allow for retrograde pyelography at the time of nephrostomy tube placement to facilitate placement of the tube, particularly if there is no severe dilation of the collecting system.

With safety and working wires in place, the flexible ureteroscope may not advance through the ureteral orifice or a segment of the ureter. The techniques discussed above may apply here (e.g. emptying the bladder, holding the wire tautly, balloon dilation). If the ureteroscope will not advance within the ureter, retrograde pyelography should be repeated to ensure there is no ureteral injury. If there is an obstructive lesion, the ureteroscope can be advanced to the level of the lesion and the area examined. With a safety wire in place, the lesion can be treated (e.g. laser lithotripsy of a ureteral stone, endoureterotomy). At any time, if the ureteroscope will not advance despite these efforts, ureteral stent placement can be performed and interval surgery planned.

If at any stage there is evidence of ureteral perforation with extravasation, a ureteral stent should be placed and the ureter should be allowed to heal before reintervention. There may be new stricture formation from a ureteral injury, and this should be investigated at the time of follow-up surgery. If ureteral avulsion occurs, stent placement should be performed if possible, and the procedure should be aborted. Percutaneous nephrostomy tube placement will likely be necessary, and ureteral reconstruction may be considered in the same sitting if severe injury has occurred to a focal segment (e.g. ureteral reimplantation for an avulsion at the level of the bladder). If more complex reconstruction is required in delayed fashion, percutaneous nephrostomy tube placement should be performed.

During manipulation of multiple wires and catheters, patients can develop bleeding from the upper tract that may obscure visualization. If visualization is significantly compromised, the procedure should be aborted and a ureteral stent placed. Bleeding from the upper tract will typically tamponade, and a stent will allow continued drainage of the kidney. Any uncorrected coagulopathy should be addressed. Severe persistent bleeding with clot retention and/or hemodynamic instability may require continuous bladder irrigation, blood transfusion, and consideration of angioembolization.

Finally, instrumentation of the urinary tract may cause urosepsis in a patient with active infection or colonization. This may occur despite the administration of prophylactic antibiotics, and in particular may occur in patients with infected stones. If a patient develops hemodynamic instability during the procedure and there is consideration for urosepsis, a stent should be rapidly placed along with bladder drainage, and broad-spectrum antibiotics administered until culture results return. If there are signs of purulent urine when accessing the upper urinary tract, cultures should be obtained and the procedure should be aborted until cultures are negative. If this occurs, a ureteral stent (+ Foley catheter) should be placed to allow for drainage of the infected urine from obstructed renal moiety.

Ureteral access in patients with urinary diversion

Retrograde ureteral access in patients with prior urinary diversion surgery has been shown to be feasible and safe, though altered anatomy may increase the complexity of these procedures [4, 5]. Success of retrograde access may vary depending on the type of diversion and the indication for URS (ureteroanastomotic stricture disease vs surveillance or stone treatment), as well as the experience of the surgeon. In one retrospective study of these patients, 21 renal units underwent attempted retrograde access for diverse indications, and 75% of attempts were successful [4]. The success rate by type of diversion was 90% (9 of 10) for orthotopic neobladders, 73% (11 of 15) for ileal conduits, and 33% (1 of 3) for Indiana pouches. All attempts to access renal units for management of suspected upper tract malignancy were successful (13 of 13 patients, 100%), while attempts were less successful in patients with anastomotic stricture disease (5 of 10, 50%).

Prior to attempted retrograde access in these patients, operative reports should be reviewed to confirm the type of diversion, type of anastomosis (e.g. Bricker vs Wallace), and likely location of the orifices. A loopogram or cystogram can be performed prior to attempted access to determine patency and location of the orifices, though we do not believe this is routinely necessary. The bladder should be initially accessed with flexible cystoscopy, particularly for pouches or conduits; rigid cystoscopy can be considered in neobladders for direct access to the orifice, particularly in cases of ureteroanastomotic stricture. If a Studer neobladder has been performed, the afferent limb should be cannulated with the cystoscope and the orifices sought. If the orifices cannot be readily identified, methylene blue or indigo carmine can be administered intravenously to view efflux of dye. Cannulation of the orifice with a flexible guidewire is then attempted (Figure 37.4). If there is difficulty with cannulation because of the location or angle of the orifice, a 5F open-ended or Bernstein angiographic catheter with a straight or angled-tip hydrophilic guidewire can be used. We recommend routine placement of a safety wire in these patients as the initial access may be challenging.

Ureteral access sheaths

Ureteral access sheaths (UASs) are used to facilitate access to the ureter during flexible URS. They are used

Image not available in the electronic edition

Figure 37.4 (A) Orthotopic neobladder with Studer limb: access into the left ureter with guidewire. (B) Orthotopic neobladder with Studer limb: cystogram reveals right ureteral reflux (reproduced from Hyams *et al.* [4], with permission).

primarily for flexible URS/holmium laser lithotripsy to enable repeated entry into the ureter with extraction of fragments or to allow for passive egress of fragments. They may also be used for repeated biopsies and treatment of suspicious upper tract lesions (e.g. upper tract TCC). UASs have become standard practice in many institutions for treatment of stone disease in particular; however, routine use of UASs is still controversial based on concern for ureteral ischemia and questions regarding the ultimate benefit of UASs for clinical outcomes. Dimensions of UASs include 11/13F, 12/14F, or 13/15F diameter, and 25–55 cm length depending on the manufacturer.

Advantages of UASs are both theoretical and practical. UASs have been shown to decrease intrarenal pressure and may decrease pyelovenous and pyelolymphatic backflow, thus decreasing absorption of irrigant [6]. UASs improve irrigant flow, which may improve visibility and help to flush out small stone fragments, as well as decrease the need for emptying of the bladder during a protracted procedure. There is conflicting evidence regarding the impact of UASs on stone-free rates [7–10], but there are reports that these are improved (Table 37.2). There is also evidence that UASs decrease the cost and operative time for treatment of renal stones, but these studies have not been rigorously designed [8].

There have been objections to routine use of UASs, including risk of acute injury to the ureter and unknown long-term risk of stricture formation [11]. The latter appears low and consistent with standard URS; however, there have been no studies with long-term follow-up [9]. Nonetheless, there is *in vivo* evidence of transient ureteral ischemia with UAS use [12]. Furthermore, placement of a UAS may be impeded by a tight ureteral orifice, which may require balloon dilation to accommodate the access sheath; this may increase the risk of extravasation in addition to the time and cost of the procedure. Ultimately use of a UAS is at the discretion of the surgeon, and it may be beneficial on either a selective or routine basis.

Placement of a UAS is safest when performed over a working guidewire in the presence of a safety wire. The two components of an access sheath include an inner dilator and an outer sheath. Placement is facilitated by use of a working nitinol guidewire or Amplatz superstiff wire (not a hydrophilic guidewire), and the access sheath is placed as a unit to the desired level within the ureter, at which point the inner component is withdrawn (Figure 37.5). It is important that all components of the access sheath are wet as the surfaces are hydrophilic. The access sheath may be secured to the drape to ensure it does not dislodge. The level of

Table 37.2 Series of ureteral access sheath (UAS) use for treatment of upper tract calculi.

Study	Number of patients	Size of sheath	Number of balloon dilations (%)	Mean size of stone (mm)	Successful placement (%)	Stone-free rate	Complications
Portis *et al*. 2006 [10]	58	14F	Not mentioned	9.4	100	54% 0 mm; <84% 2 mm; 95% <4 mm	Ureteral perforation (3)
Kourambas *et al*. 2001 [8]*	23	12/14F x 20, 28, 35 cm	1 (4.3)	137	91	78.9%	Ureteral obstruction secondary to edema requiring stent placement (1), deep vein thrombosis (1)
Delvecchio *et al*. 2003 [9]	71	10/12F (8), 12/14F (56), 14/16F (7) x 20, 28, 35, 55 cm	6 (8.4)	107	100	77.4% 0 mm; 90.3% <4 mm	Asymptomatic stricture (1)
L'Esperance *et al*. 2005 [7]**	173	12/15F, 35 cm	Not mentioned	87	100	75%	None

*Prospective randomized study of UAS (23) versus no UAS (21); there was no difference in stone-free rate (78.9% vs 85.7%; $P = .78$)

**Retrospective comparative cohort study of UAS (173) versus no UAS (83); stone-free rate was improved overall by use of a UAS (79% vs 67%; $P = .04$)

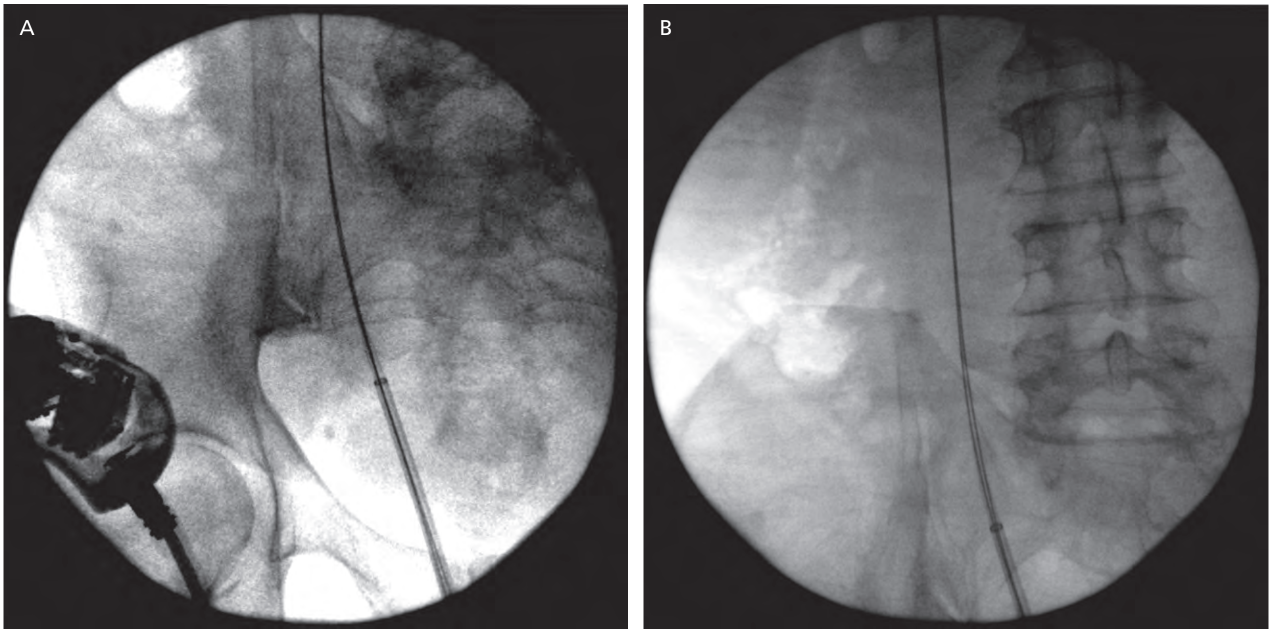

Figure 37.5 Ureteral access sheath placed in (A) distal ureter and (B) mid ureter.

placement depends on the clinical scenario; for a renal stone, placement in the proximal ureter is typical to protect as much ureter as possible during entry and re-entry.

Placement of a UAS can be compromised by an anatomically tight ureter or ureteral stricture disease. If the UAS cannot be placed through the orifice, balloon dilation may be performed. While some surgeons dilate the orifice on a regular basis for UAS placement, others will simply abort use of the sheath and continue without it. It has not been rigorously studied whether one approach is superior to the other from the standpoints of safety or stone clearance.

Finally, when placing an UAS, it important to be aware of small ureteral stone fragments that can be trapped alongside the sheath and are at risk for being pushed submucosally. If unrecognized this can lead to an impacted stone, or possibly a submucosal stone that can cause ureteral obstruction secondary to stricture formation.

We recommend placing a ureteral stent at the end of any procedure in which a UAS is used. Rapoport *et al*. retrospectively reviewed a series of consecutive patients who underwent URS for renal and ureteral stones, and found that use of a UAS without postoperative stenting significantly increased the risk of unplanned emergency room visits with increased emergency computed tomography (CT) scans, hospital readmission, and urgent decompression [13].

A radially dilating balloon UAS has recently been evaluated in the porcine model and appears to cause less urothelial damage compared to traditional UAS while enabling higher flow rate; this device still requires formal testing in human subjects [14]. Although preliminary evaluations have been favorable with regards to ease of use and success in placement in humans, no follow-up studies have been done with regards to clinical success, stone-free rate, operative time, and complication rates.

Conclusions

Access to the ureter for flexible URS is typically straightforward, but can be complicated by both anatomic and disease factors. Anticipation of the "next step" and planning for difficult access can maximize the likelihood of success in these cases. Repeated entry to the ureter for flexible URS can be facilitated by use of a UAS, though the precise risk-to-benefit ratio of UAS is not known.

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CHAPTER 38

Ureteroscopic Management of Ureteral Calculi

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Introduction

Improvements in technology over the last 10–15 years have led to an increased ability to successfully manage ureteral calculi using a variety of methods. Although extracorporeal shock-wave lithotripsy (ESWL), antegrade percutaneous approaches, and laparoscopic ureterolithotomy are options, the mainstay in the treatment of patients with ureteral calculi continues to be retrograde ureteroscopic (URS) stone removal. Refinements in URS technology, as well as the development of improved laser techniques and advances in ancillary equipment, such as baskets, graspers, and others, have led to a situation in which almost all ureteral calculi can be successfully managed in a single procedure using URS.

Despite these advances, the selection of the single best approach to treat patients with ureteral stones remains controversial, especially given the complexity of today's changing healthcare environment. As there is increasing public focus on less invasive treatment strategies, it should be kept in mind that such approaches may in some cases lead to higher treatment failure rates with the need for secondary procedures. Additionally, a variety of economic factors have increased in importance in all areas of healthcare, and ultimately the most cost-effective approach to ureteral stones may be deemed best for all patients.

In this chapter, we will review the use of URS in relation to other treatment options for patients with ureteral calculi and discuss the wide variety of equipment and instruments that can be used with this procedure.

Treatment options

Many patients with ureteral calculi can be managed conservatively without immediate intervention. Observation alone is a reasonable approach for those patients with mild-to-moderate symptoms that can be controlled with oral analgesics, and those who do not have any factors that would warrant immediate intervention. These factors include infection, compromise of renal function, stone in a solitary kidney, nausea and vomiting preventing adequate hydration, and inability to adequately control pain. The likelihood of stone passage also has an important impact on the decision to proceed with intervention versus a period of observation with the hope for spontaneous stone passage. The most important factor in predicting whether a ureteral calculus will pass is the width of the stone. Location of the stone (proximal, mid or distal ureter) and impaction also have an effect on the relative likelihood of stone passage [1, 2]. In general, the accepted cut-off predicting a greater chance of stone passage is a size of 5 mm. Stones less than 5 mm in diameter have been reported to pass spontaneously in 70–90% of patients with distal stones and 30–80% of those with proximal stones [1]. In contrast, stones greater than 5 mm have a much lower likelihood of stone passage at 10–50% in general, with improved rates for those in the distal ureter [1, 2].

The decision to proceed with observation as an initial management approach is often largely based on patient preference. With the exception of the indications for

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immediate intervention mentioned above, most patients can at least be offered the opportunity to pass the stone spontaneously. In our experience, some patients with ureteral calculi who have well-controlled symptoms react negatively if a urologist is "too aggressive" in recommending an immediate procedure, and may lose confidence in this urologist and end up seeking an alternative medical opinion. On the other hand, a frank discussion of the relative likelihood of stone passage is important in helping the patient decide whether immediate intervention is appropriate. Since an accurate prediction of the time to spontaneous stone passage is very difficult, patients must understand that the quoted statistics on stone passage are largely based on waiting times of up to 4–6 weeks. In many cases, due to work and personal considerations and the uncertain nature of when a stone will pass, patients may opt for stone removal rather than waiting.

The use of pharmacologic therapy to increase the likelihood of stone passage and decrease the interval until the stone passes has become increasingly popular [3–6]. Seitz *et al*. conducted a meta-analysis of published literature concerning the use of medical expulsive therapy in patients with ureteral stones [5]. For 47 randomized controlled trials they assessed the use of alpha-blockers and calcium channel blockers in patients with untreated ureteral calculi of varying sizes. Their results demonstrated that the use of either medication led to a higher and faster stone expulsion rate as compared to the control groups. In addition, treated patients had lower analgesic requirements, fewer episodes of colic, and fewer hospitalizations. Although other studies have not shown a difference in outcome when using alpha-blockers compared to no treatment in terms of stone passage rates [3], overall the risks associated with short-term use of these medications is minimal and it has now become an accepted practice to administer alpha-blockers in patients with ureteral stones. It is important that urologists continue to educate their colleagues in emergency medicine regarding this practice [4, 6].

Ureteroscopy

In performing URS, there are two basic choices of endoscopes, flexible and semi-rigid instruments (see Chapter 34). Semi-rigid instruments have fiberoptic bundles, range in size (external diameter) from 6.9F to 10F and may have single or dual working channels. There are several advantages associated with the use of semi-rigid ureteroscopes. In most cases, visualization is superior and it is easier for the operating urologist to control the instrument and manipulate accessory equipment such as baskets, graspers, etc. The diameters of the working channels of semi-rigid ureteroscopes are usually wider than those seen with flexible instruments, which allows for easier use of accessory equipment and improved irrigant flow. When removing stone fragments, repeated passage of the scope into the ureter is generally easier than when using a flexible instrument. In addition, semi-rigid instruments are often more durable than flexible instruments, leading to less breakage and lower cost associated with long-term use. As the diameter of these instruments has reduced, they can usually be safely passed into the ureter without the need for active ureteral dilation. Semi-rigid ureteroscopes are best suited for stones in the distal ureter below the crossing iliac vessels and may be more difficult to pass proximally in men, especially in those with large prostates.

The greatest technologic advances in URS over the last several years have come in the area of flexible instruments. Initially, lack of durability of flexible ureteroscopes was a significant problem, and expensive and frequent need for repair was the norm in most busy endourologic practices [7]. However, improvements have been made and today's flexible instruments are generally less prone to breakage than earlier generations of scopes [8]. In addition, the degree of deflection (less important when treating ureteral stones than those in the kidney), size of the working channel, and overall visualization have also been significantly improved. A significant advance has been the development of fourth-generation digital flexible ureteroscopes (see Figure 34.9) [9]. Multescu *et al*. compared an Olympus digital ureteroscope and a standard Storz instrument and found that the digital scope had significantly greater maneuverability and visibility [9]. There was also less deflection loss with the digital scope when an accessory instrument was present in the working channel and irrigant flow was also superior. One disadvantage of the digital scopes are that they have a slightly larger tip that may also be more blunt, thus making access to the ureter and passage through narrow segments of the upper urinary tract more difficult. In most cases, we have found that it is necessary to have a ureteral access sheath in place in order to pass the digital ureteroscope into the ureter, whereas the standard flexible scope can be passed, if desired, without this sheath.

Overall, it is usually best to use a semi-rigid instrument if this can be safely passed to the level of the stone, even if the stone is located in the proximal ureter. As discussed above, the semi-rigid instrument is often easier for a single operating surgeon to use and usually allows for better visualization and irrigant flow. The semi-rigid scope is particularly well-suited for patients who have an indwelling stent prior to URS as this leads to passive dilation of the ureter, thus making passage of the instrument easier. However, if resistance is encountered, the semi-rigid instrument should never be forced more proximally in the ureter and instead switching to a flexible instrument is advisable.

Patient preparation and preoperative evaluation

Radiographic evaluation of the urinary tract is essential prior to URS and most patients will have undergone a noninfused computed tomography (CT) scan of the abdomen and pelvis. Although no contrast is used with this study, the ureteral anatomy can usually be well-defined. Additional information can be obtained at the time of the procedure by performing a retrograde pyelogram if necessary.

Some patients will initially present with urinary tract infection or urosepsis secondary to the obstructing ureteral calculus. This situation may be more commonly seen in diabetic patients or those who are immunocompromised. In this circumstance it is best to simply decompress the upper urinary tract with either ureteral stent placement or percutaneous nephrostomy tube insertion. Attempts to perform URS in the face of untreated or inadequately treated infection may lead to significant bacteremia with potentially disastrous complications. Even in patients without overt signs of infection or sepsis, it is appropriate to perform urinalysis and urine culture and ensure any infection is adequately treated prior to URS.

Informed consent prior to URS should include a discussion of the risks of ureteralinjury or perforation. Although most injuries can be managed simply with stent placement alone, there are rare circumstances in which more extensive treatment may be necessary. In addition, the risks of ureteral stricture and the need for treatment of this complication should also be discussed.

Surgical technique

URS is performed in most cases using general anesthesia. However, intravenous sedation alone or regional anesthetic techniques may be appropriate as clinical circumstances dictate. Allowance for adequate fluoroscopic visualization of the entire urinary tract is critical and provisions for radiographic monitoring should be made in all cases. In general, patients are placed in a dorsal lithotomy position with the contralateral lower extremity maximally abducted to facilitate access to the involved ureter. Broad-spectrum antibiotics are routinely administered prior to URS.

Increasingly, issues related to the use of anticoagulant medications prior to urologic surgical procedures have arisen. If such medications can be temporarily discontinued perioperatively with minimal risk to the patient, it is reasonable to do so. However, URS can be safely performed if necessary while patients remain anticoagulated. Turna *et al*. retrospectively analyzed 37 patients undergoing flexible URS while on warfarin, clopidogrel or Aspirin, and compared them with a matched cohort of patients treated without anticoagulation [10]. No procedure had to be terminated due to poor visibility from bleeding and there was no significant difference in intraoperative or postoperative complications in the two groups.

All URS procedures should begin with surveillance of the bladder with particular attention paid to the location and configuration of the ureteral orifices. If the ureteral stone is readily visible at the expected location on initial fluoroscopic imaging, we generally do not perform a retrograde pyelogram initially since the injected contrast may obscure visualization of the stone. However, if the stone is not easily seen or there is a question regarding the ureteral anatomy, then it is best to perform a retrograde pyelogram to define the involved collecting system and ureter. The next step is passage of a wire past the stone and into the renal pelvis. A variety of guidewires are available, although we generally prefer a hydrophilic wire with a curved tip as this usually is the easiest to manipulate around the stone with minimal trauma to the ureter. Once the wire is confirmed to be in the renal pelvis, a second guidewire may be placed as a safety wire. In the less common situation in which a wire cannot be placed by the stone, the ureteroscope can be passed to the stone and then a wire can often be manipulated by the stone under direct visualization. If this is not possible, then careful fragmentation of the stone can be performed to free some space in the ureter alongside the stone and then the wire can be placed. If a semi-rigid instrument is to be used, this can often be placed alongside the initial wire without the need for a second wire. If a flexible ureteroscope is to be used, this is generally passed over a wire or through a ureteral access sheath. In this case, the wire is usually removed after the scope is in position, so it is best to initially place a second wire as well that can be maintained throughout the procedure as a safety wire.

When passing the semi-rigid ureteroscope, it is important never to try to advance the instrument if visualization is limited or there is significant resistance, even if going over a guidewire. In most cases, active dilation of the ureter is not needed as the instruments are small enough to pass. However, in the presence of a stricture or in selected other cases, active dilation using a balloon dilation catheter or progressive dilators can be considered. Irrigation by an assistant using a hand-held syringe or other pumping device is often helpful to improve visualization; however, it is important to use this judiciously to avoid displacement of the stone more proximally. Pressure pumps are also available, although we prefer to use a hand-held syringe, which allows better control of the force with which the irrigant is delivered. Similar issues exist for the flexible ureteroscope, which is almost always passed initially over a wire to the level of the stone. As mentioned above, ureteral sheaths are available and are very helpful, particularly with flexible endoscopy, as they often facilitate passage of the instrument and allow for multiple insertions of the scope to remove fragments, etc. If difficulty is encountered in safely performing the procedure, it is always best to simply place a ureteral stent and allow for passive ureteral dilation, which generally makes a secondary URS procedure much easier to perform at a later date.

Stone fragmentation and removal (see Video 38.1)

Once the ureteroscope has been successfully advanced to the level of a ureteral stone, a decision needs to be made whether to try and remove it intact or fragment the calculus. In previous years, when larger instruments were routinely used and the ureter was frequently dilated with a balloon or by another method, it was more common to remove stones intact. However, the advent of smaller scopes that may be passed without active dilation has made it more difficult to directly extract larger stones without risking damage to the ureter. As a general rule, when in doubt about whether a stone can be successfully removed without fragmentation, it is best to err on the side of caution and break it into pieces prior to removal. The two most commonly used methods to fragment ureteral stones are laser lithotripsy and pneumatic lithotripsy. The holmium:YAG laser is used commonly and offers several advantages in stone fragmentation. First, it can be used to fragment all stones irrespective of composition or hardness using small diameter fibers. Second, the smaller fibers can be easily passed through flexible endoscopes with limited effect on the ability to provide irrigation to ensure adequate visualization. When working in the ureter, there is no significant concern about limitations in the ability to deflect the instrument as may occur when dealing with renal stones, particularly those in the lower calyces. Another advantage is the ability to ablate the stone, converting it to dust particles that do not have to be actively removed. The main disadvantage of the holmium:YAG laser is the associated cost of the instrument itself and of the disposable fibers.

Pneumatic lithotripsy most commonly involves the use of the Lithoclast device. This instrument is also highly effective in fragmenting stones and is generally associated with lower costs than those seen with the holmium:YAG laser as nondisposable probes are available. Disadvantages of pneumatic lithotripsy include the rigid probes which cannot be used with a flexible ureteroscope and the increased risk of retrograde stone propulsion. Mandal *et al*. compared laser and pneumatic lithotripsy for ureteral stones in a randomized, prospective study and found that both methods were safe and effective [11]. However, the immediate stone clearance rate was significantly better in the laser group and stone migration occurred in 16% of cases using the pneumatic device. Similar results when comparing laser and pneumatic lithotripsy in treating ureteral stones were reported by Maghsoudi *et al*. [12].

Once the stone has been adequately fragmented, or if it is to be removed intact, a variety of devices can be used for stone retrieval. Stone baskets are available in a variety of shapes and configurations and personal preference is probably most important in selecting which to use. In most cases, our preference is a tipless, nitinol basket when using the flexible instrument, and stone graspers with a rigid instrument. The advantage of the graspers is that the stone can be more easily disengaged if it is too large to remove and it will generally fall out of the graspers before significant damage to the ureter can occur. The baskets hold the stones more securely, but if the size of the calculus has been misjudged, it may be more difficult to disengage the stone from the basket for further fragmentation. In addition, the ureter can be damaged as the stone and basket are pulled distally if too much force is applied.

Another decision that needs to be made after the stone has been fragmented in the ureter is whether to try and remove all the fragments during the procedure or to allow them to pass later. It is generally our practice to remove all fragments from the ureter and this approach is supported by the results of a recently published study [13]. Schatloff *et al*. randomized 60 patients undergoing URS with laser lithotripsy to intraoperative fragment retrieval or spontaneous fragment expulsion. Although the results were somewhat clouded by variations in postoperative stent placement and the etiology of symptoms following the procedure, there was a significantly higher rate of unplanned medical visits in the group with incomplete fragment extraction. In addition, there was a trend towards higher rates of rehospitalization, residual stones, and the need for ancillary procedures in this group [13].

The role of postoperative stenting after URS stone removal is controversial and will be addressed in Chapter 46.

When performing URS stone removal, prevention of inadvertent retrograde calculus migration is important in achieving a successful outcome. This is particularly true when using a semi-rigid instrument since it may not be possible to advance the scope further proximally in the ureter to reach the stone if it has been displaced. In some situations, a flexible ureteroscope may not be available and some surgeons may not be comfortable performing flexible endoscopy. A variety of approaches are available to help avoid stone retropulsion. First, when using the holmium:YAG laser to fragment the stone, we try to place the fiber on top of the stone rather than on the most distal portion, so that the energy delivered to the calculus is less likely to push it more proximally. Second, some semi-rigid instruments have two working channels which allow the stone to be engaged in a basket placed through one channel while the laser fiber or pneumatic probe is placed through the other channel. In addition, baskets that can accommodate a laser fiber to be placed through them are also available. Third, instillation of lidocaine jelly proximal to the stone appears to help prevent retropulsion [14]. Zehri *et al*. used a 5F ureteral catheter advanced beyond the stone to instill 2 mL of lidocaine jelly. Semi-rigid URS was then performed and the stones were fragmented using a pneumatic lithotripsy device. When comparing groups using lidocaine jelly and a randomized control group treated without, there was significantly less proximal stone migration and a better stone-free rate at 2 weeks in those receiving lidocaine [14]. Finally, a variety of antiretropulsion disposable devices are available [15–17]. In general, these devices are placed proximal to the stone and are then deployed in a configuration that prevents stone migration as fragmentation occurs. They may also help in removal of stone fragments as they are pulled distally after fragmentation is completed. Reduction in stone retropulsion using these devices has been demonstrated both *in vitro* and in clinical assessments [15–17]. The primary disadvantage of these antiretropulsion devices are the associated cost. Overall, when a flexible ureteroscope is available and the operating surgeon is comfortable and experienced with its use in the proximal ureter and kidney, stone migration is a minor concern and can usually be avoided with simple measures as described above. However, if semi-rigid URS is the only available option, then retropulsion is a greater concern since there is a risk that the procedure will not be completed successfully, leading to the need for secondary approaches, such as ESWL, if the stone moves into the proximal ureter or kidney before it is adequately fragmented. In such circumstances, extra efforts to avoid stone migration, such as the use of retropulsion devices, may be appropriate.

Complications

Advances in fiberoptic technology and the availability of smaller and flexible instruments have led to an overall improvement in the safety of URS stone removal. However, complications may still occur due to mucosal injury from the endoscope itself or from the use of lithotripters to fragment stones within the ureter. The most common complication is ureteral perforation or the development of a false passage in the ureter. In general, this should be easily recognized at the time of the occurrence or when a retrograde pyelogram is performed at the completion of the procedure. As long as a safety wire is left in place, minor perforations generally are easily managed by the placement of a ureteral stent which is left in place for up to 4–6 weeks depending upon the extent of the injury. There is an increased risk for the development of ureteral strictures after perforation has occurred, so imaging 6–12 weeks after the stent is removed is essential in these cases, even if the patient is asymptomatic [18]. If a stent cannot be placed or if the injury is more extensive, then a percutaneous nephrostomy tube may be placed.

Overall, the incidence of strictures following URS stone removal is 1–2% [18, 19]. In addition to ureteral injury, the extent and duration of stone impaction may increase the risk of stricture formation. Some authors have recommended routine imaging following stone removal since silent obstruction may occur. Weizer *et al*. reported that seven of 459 patients undergoing URS stone removal were asymptomatic despite the development of ureteral strictures [19]. Therefore, they recommended that all patients undergo imaging of the upper urinary tract within 3 months after stone removal. Adiyat *et al*. investigated the need for routine postoperative imaging in 253 patients undergoing URS stone removal [18]. While the overall incidence of stricture formation in this group was 1.4%, 0 of 158 patients with uncomplicated procedures developed strictures. Complicated patients were defined as those with ureteral perforation, stone impaction or the need for balloon dilation of the ureter. Therefore, these investigators concluded that routine follow-up imaging is not essential after uncomplicated URS.

The most serious complication of URS stone removal is ureteral avulsion, which fortunately is a rare occurrence. Ureteral avulsion most often results from trying to pull a stone that is too large to be removed intact down the ureter in a basket. The treatment of ureteral avulsion depends on the extent and location of the injury. If the distal ureter is the site of injury, avulsion can be managed by ureteral reimplantation with the use of a psoas hitch or Boari flap. For injuries that occur in the mid or proximal ureter, management can be quite challenging and may require ureteral substitution, autotransplantation of the kidney, or even nephrectomy. Surgery is best performed immediately to avoid the development of edema and inflammation, which can hamper a successful outcome. If a delay in treatment is necessary, then a nephrostomy tube should be placed.

Conclusions

URS stone removal has become the procedure of choice for most patients with ureteral stones. With modern fiberoptic technology, the availability of effective lithotripsy devices, such as the holmium:YAG laser and pneumatic devices, and flexible endoscopes, the success rate in removing ureteral stones at all levels of the ureter is excellent. Issues related to stone migration can be effectively managed using a variety of techniques and disposable devices that are readily available, allowing for a minimal risk of the need for secondary procedures to remove stones. Overall, URS stone removal is highly effective, with a low risk of complications, and it can be performed successfully and safely by most urologists.

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CHAPTER 39

Ureteroscopic Management of Renal Calculi

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Introduction

During the last three decades treatment modalities for renal calculi have undergone several significant changes. Prior to the introduction of extracorporal shock-wave lithotripsy (ESWL), open surgical removal of stones from the upper urinary tract was the treatment of choice. In the 1980s ESWL was introduced and open surgical treatment of renal calculi was only performed in patients with large stone burden. As ESWL only fragments renal stones, stone passage via the ureter is necessary. Although ESWL is a treatment modality with low morbidity, the stone-free rates are disappointing; only up to 50% even for lower pole stones. This led to the invention of percutaneous stone removal. By means of conventional nephroscopes, renal calculi can be removed with a percutaneous approach to the kidney. Percutaneous nephrolithotomy (PCNL) offers a significant increase in stone-free rate, but the morbidity with PCNL is significantly higher than with ESWL. This dilemma could be solved by using a retrograde access to the renal calyceal system.

In the 1990s, flexible endoscopes became available and these could reach the upper urinary tract. However, these instruments were disadvantaged by their diameter, initially between 9F and 13F, and the limited ability to deflect the tip of the instrument. Also, no disposables were available to facilitate the access to the ureter. In the late 1990s the development of new flexible ureteroscopes began. There was a significant improvement in the deflection angle, which now reaches 270° [1, 2]. Another important improvement was the decrease in diameter to 7.5–9F. Simultaneously, ureteral access sheaths became available, allowing easy access to the ureter. Special baskets and stone retrieval systems, such as tipless baskets and "Graspit," were invented. Another very important step in the introduction of endoscopic treatment of renal calculi was the introduction of holmium laser systems. Due to the limited diameter of the working channel, ultrasound probes and ballistic lithotripsy were almost impossible to use. Only laser lithotripsy allowed the treatment of all upper urinary tract calculi. Due to the small caliber of the laser fibers, deflection of the flexible endoscopes is not significantly reduced.

Today there is a great variety of flexible ureterorenoscopes from different companies. These allow almost all parts of the calyceal system to be entered. In combination with particular disposables that facilitate the access to the upper urinary tract, flexible ureterorenoscopy (URS) has become an essential part of the treatment of renal calculi. Due to the low morbidity of flexible endoscopic treatment of renal calculi and the enhanced stone-free rate in comparison to ESWL, it is expected that primary endoscopic treatment of renal calculi will probably become the treatment of choice (Figure 39.1).

Indications

The different treatment modalities open to patients suffering from upper urinary tract calculi are: ESWL, retro-

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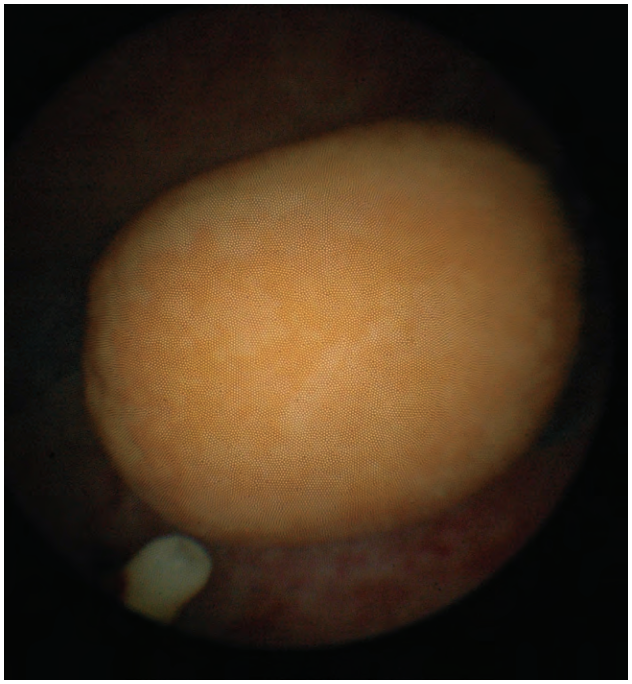

Figure 39.1 Endoscopic view of a renal pelvic stone by means of a flexible ureterorenoscope. Stones up to 1 cm in diameter are particularly suitable for retrograde flexible ureterorenoscopy.

Table 39.1 Factors influencing the decision to treat renal calculi endoscopically.

- Stone localization
- Stone size
- Stone analysis (if available)
- Morphology of the urinary tract
- Complication rate
- Patient's preference
- Economic aspects
- Technical equipment

Table 39.2 European Association of Urology recommendations for the treatment of upper urinary tract calculi.

	<20 mm	>20 mm
Radio-opaque stones	1. ESWL 2. PCNL 3. Flexible URS	1. PCNL 2. ESWL (±stent)
Infection stones	1. Stent, ESWL, antibiotics 2. PCNL, antibiotics 3. Flexible URS	1. PCNL, antibiotics 2. ESWL (±stent), antibiotics 3. ESWL, PCNL, antibiotics
Uric acid stones	1. Chemolitholysis 2. Stent, ESWL, chemolitholysis	1. Chemolitholysis 2. Stent, ESWL, chemolitholysis
Cystine stones	1. ESWL, PCNL 2. Flexible URS 3. Laparoscopic/ open surgery	1. PCNL 2. PCNL, ESWL 3. PCNL, flexible nephroscopy 4. Laparoscopic/ open surgery

ESWL, extracorporeal shock-wave lithotripsy; PCNL, percutaneous nephrolithotomy; URS, ureterorenoscopy.

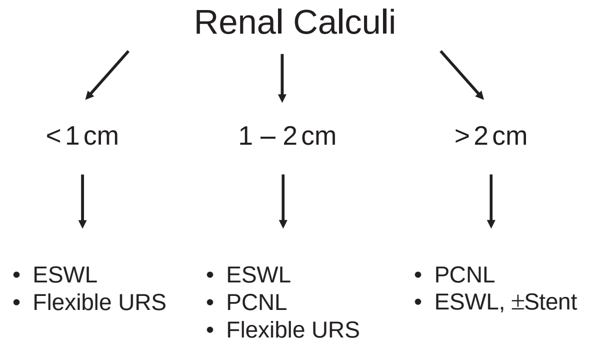

Figure 39.2 Algorithm showing the German Association of Urology guidelines for the treatment of upper urinary tract calculi. ESWL, extracorporeal shock-wave lithotripsy; PCNL, percutaneous nephrolithotomy; URS, ureterorenoscopy.

grade flexible URS, conventional PCNL, miniaturized PCNL (mini-perc), and open surgical and laparoscopic removal. The decision as to which treatment modality should be recommended is dependent on several stone characteristics (size, locaation, composition, if available), as well as morphology of the urinary tract, complication rate, patient preference, available technical equipment, and economic aspects (Table 39.1).

If it is intended to treat renal calculi by means of flexible URS, it should be remembered that all fragments of the renal stone have to be taken out via the ureteral access sheath. Increasing stone size is associated with increasing operating time and increasing risk of pyelonephritis. Only a limited number of reports in the literature describe the indications for endoscopic management of renal calculi. The guidelines of the European Association of Urology (http://www.uroweb.org/?id=218&gid=13) recommend flexible URS only as a third-line therapy in patients suffering from renal stones with a diameter less than 2 cm. In stones that exceed a diameter of 2 cm, flexible ureterorenscopy is not recommended (Table 39.2). The joint European Association of Urology and American Urological Association Urolithiasis Guidelines Panel has recommended treatment of ureteral stones by means of an endoscopic approach, but flexible ureterorensocopy as a primary approach to upper urinary tract calculi has so far not been recommended. The German Association of Urology recommends flexible URS in stones with a diameter up to 1 cm as a second-line therapy and in stones with a diameter from 1 to 2 cm as a third-line therapy (Figure 39.2).

Table 39.3 Results of flexible ureterorenoscopy in upper urinary tract calculi in a high-volume center (n = 802).

Mean stone size (mm^2)	57.5
Adjuvant shockwave lithotripsy (%)	23.9
Holmium laser lithotripsy (%)	46.6
Mean operating time (min)	49.6
Stone-free rate (%)	86.3
Retreatment rate (%)	11.5
Pyelonephritis (%)	9.8
Perforation (with complete convalescence after double-J stenting) (%)	1.7
Major complications (%)	0.0

Table 39.4 Indications for retrograde flexible ureterorenoscopy in renal calculi.

Proximal ureteral stones, if rigid ureteroscopy is not possible or suitable
Residual renal pelvic and calyceal stones after shock-wave lithotripsy, rigid ureteroscopy or percutaneous procedures
Diverticular stones (incision of the neck of the diverticulum and removal of the stone)
Primary treatment of renal pelvic and calyceal stones on an individual basis

Thus, there is only a second-line indication for flexible URS in the treatment of upper urinary tract calculi. Therefore, the decision to use flexible URS as the primary approach in patients with upper urinary tract calculi must be made on an individual basis. Surgeons should inform patients about possible side effects, stone-free rates, and the fact that flexible URS is as yet not recommended in guidelines. Also, no large randomized trials concerning flexible URS have been reported so far The experience with flexible URS in the treatment of renal stones as a primary approach mainly comes from single-center studies(Table 39.3).

A summary of the current accepted indications for retrograde flexible URS is given in Table 39.4.

Access to the upper urinary tract

In contrast to rigid URS, flexible scopes cannot usually pass the ureteral orifice without additional help, due to the ability to deflect the tip of the instrument and the configuration of the tip.. There are two main possibilities to solve this problem: (1) insert a guidewire into the ureter and pass the flexible scope over the guidewire, and (2) make use of a ureteral access sheath.

Guidewires

With the use of a guidewire it is very easy to reach the ureter and the upper urinary tract. However, there are disadvantages with this method. There is a risk of altering the ureteral orifice as the tip of the flexible instrument may be sharp. Once the instrument is inserted, irrigant cannot flow back to the bladder, and the limited irrigation may restrict the endoscopic view. Another consequence is the increased risk of febrile urinary tract infections due to an enhanced irrigation pressure inside the ureter and calyceal system. If the treatment of stones requires several passages of the ureter in order to remove the fragments, the approach to the ureter will be lost if the guidewire was inserted for this purpose and no access sheath had been used. In this case the use of a guidewire is time consuming. In addition, the sharp edges of stone fragments, which are taken out through the ureter, may alter the ureteral wall, and cause bleeding and a poor endoscopic view.

Ureteral access sheaths

Ureteral access sheaths are easy to use in the approach to the ureter. Access sheaths with different diameters are available from different companies. First a guidewire is inserted under X-ray control, and then the access sheath is inserted over the guidewire. The access sheath itself consists of two parts: the inner part with a tip to dilate the ureteral orifice, and an outer part made from an enforced material to avoid any buckling. The size of the ureteral access sheath chosen will depend on the particular situation of the patient. If the ureter has a double-J stent or the patient is female, a 14/16F ureteral access sheath is recommended. The decision as to which ureteral access sheath to use should be taken with care and should consider the morphology of the ureter.

Another important consideration is the stone burden to be treated. The larger the stone burden and thus the greater the number of stone fragments to be expected, the larger the ureteral access sheath should be. The ureteral access sheath allows easy re-entry of the calyceal system and multiple passages for removal of stone fragments, which is a significant advantage over the use of a guidewire in flexible URS.

Another advantage that should be mentioned is the fact that the pressure of irrigant in the calyceal system is low, due to the space between the flexible scope and the inner wall of the access sheath. Febrile infections, which may be caused by an enhanced pressure, occur very rarely when ureteral access sheaths are used in the treatment of renal calculi [3].

Ureteral access sheaths were previously suspected of causing ureteral alterations such as strictures. However, there is evidence that their use does not increase the rate of ureteral strictures [4].

In summary, access to the upper urinary tract by means of ureteral access sheaths is quite easy and safe if the size of sheath is chosen according to the morphology of the urinary tract, stone size, and number of expected stone fragments to be removed. They are a necessary auxiliary tool in the treatment of renal calculi [5–7].

Lithotripsy in flexible ureterorensocopy

Intracorporeal lithotripsy plays an important role in flexible URS. As all stone fragments have to be taken out through the ureteral access sheath, the aim of lithotripsy is to produce fragments of a size that can be withdrawn through its inner cross-section. The more successful lithotripsy is at this, the faster the patient will become stone free.

There are different lithotripsy devices available: ballistic lithotripsy, ultrasound lithotripsy, electrohydraulic lithotripsy, and laser lithotripsy. Their most important aspect is that they should not influence the ability to deflect the tip of the instrument. Ballistic lithotripsy does not play an important role in flexible URS as its flexible probe decreases significantly the deflection angle of the tip of the flexible scope [8]. As there are no flexible probes available for ultrasound lithotripsy, it also is not suitable for flexible URS. In principle, electrohydraulic lithotripsy is possible in flexible URS, but due to the difficulty controlling the energy applied to the stone, it cannot be recommended in flexible lithotripsy.

The lithotripsy device of choice in flexible URS is a laser. Two different kinds of laser suitable for the treatment of renal calculi are available: the holmium:YAG and neodymium:YAG lasers. Both employ deflectable laser fibers. Their main difference is that the holmium laser can fragment all types of stone, whereas the neodymium:YAG laser does not fragment cystine stones. The size of stone fragments can be defined during lithotripsy by an experienced endourologist [9].

In summary, the lithotripsy device of choice is the holmium laser. Using small-caliber probes, the deflection of the tip of the flexible scope is not noticeably decreased.

Stone retrieval systems

In the age of rigid ureteroscopy, reusable forceps were the device of choice to remove stones. Due to the limited diameter of flexibles scopes, new stone retrieval devices have been invented. The diameter of modern small-caliber devices is about 1.1F, 1.3F or 1.5F, which allows maximum irrigation flow and maximum deflection of the tip of the instrument, i.e. almost all parts of the calyceal system can be reached by means of these modern devices. The combination of flexible scopes and minimally invasive flexible stone retrieval devices gives a high stone-free rate after flexible URS.

In contrast to the Dormia baskets used in the ureter, tipless baskets are used in the renal calyceal system to "catch" calyceal stones located at the calyceal wall. As there is no overlaying tip, which may cause bleeding at the calyceal wall, tipless baskets provide a clear view [10]. Recently these tipless baskets have been modified to further facilitate the catching of stones (Figure 39.3). Single-use graspers or forceps are also available, but in practice these forceps are not as reliable in catching stones as the tipless baskets.

Given the cross-section of the retrieval device, a decrease of irrigant flow and deflection angle has to be accepted [11].

Definition of "stone free"

In order to compare the effectiveness of modern endourologic treatment modalities with earlier results for ESWL, it is important first to define what is meant by the term "stone free." In ESWL studies, a patient was considered to be stone free if the diameter of residual fragments did not exceed 4 mm. Whether there are residual fragments or not can be determined by X-ray [kidneys, ureter, and bladder (KUB)]; computed tomography (CT) scan or ultrasound examination, but all these methods are limited by inter- and intra-observer variation. Also, not all radio-opaque findings on X-ray examination correspond to intraluminal stones. A study of 400 flexible URSs showed that 12% of all calcifications detected by means of X-ray examination were parenchymal calcifications, which do not need to be treated (Figure 39.4). If endourologic treatment modalities are used, stone-free status is determined under direct endoscopic vision. If flexible URS or percutaneous techniques are performed, there should be no residual fragments. Thus the results of ESWL cannot easily compared to the results of endoscopic procedures, and the greater stone-free rate achieved with flexible URS compared with ESWL is probably an underestimate.

Treatment

Small stone burden

Renal stones with a diameter of less than 1 cm can easily be treated by retrograde flexible URS (see Video 39.1). As mentioned above, the diameter of the access sheath should be chosen according to the size of the stone, morphology of the urinary tract, and expected stone composition. Unfavorable stone localizations, such as in lower poles, can be managed by the relocation of the stone to the renal pelvis. In this position the stone can easily be fragmented and all fragments can be removed.

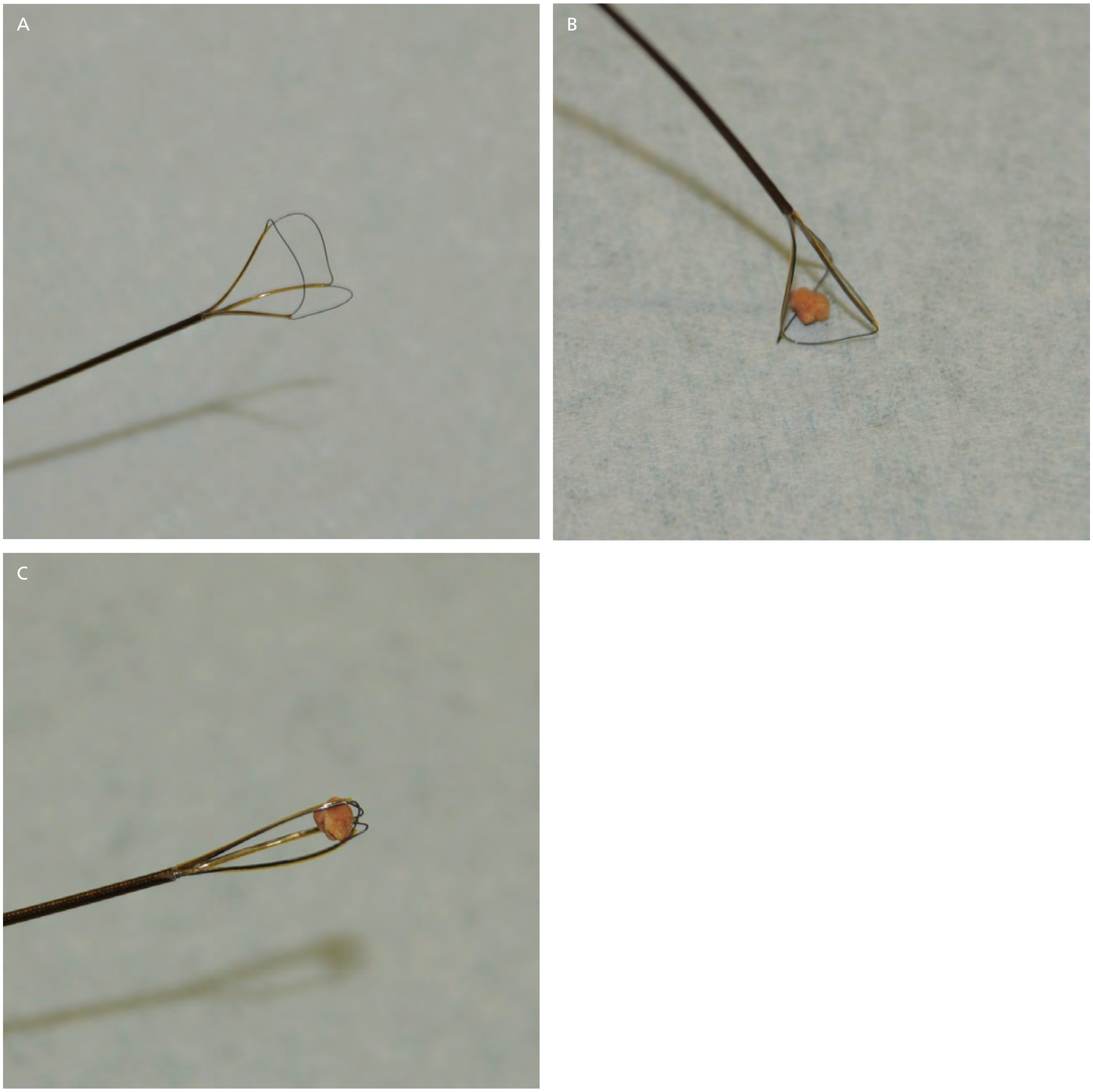

Figure 39.3 Special nitinol devices facilitate the removal of calyceal stones. (A) Opened basket (N-Gage, Cook Urological, Bloomington, IN, USA). (B) Basket positioned to catch the stone. (C) Basket with caught stone.

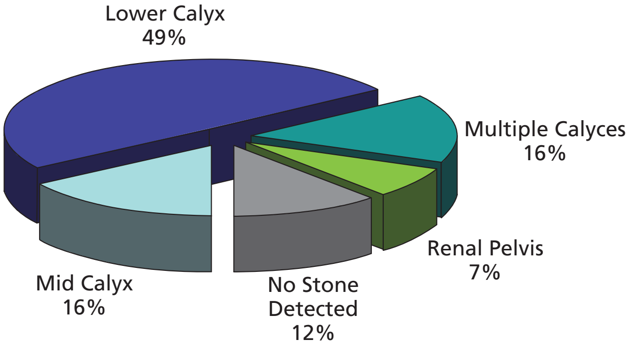

Figure 39.4 Distribution of stones in upper urinary tract calculi (n = 400).

Stones that are too large to be accommodated by the inner diameter of the ureteral access sheath can sometimes be extracted by simultaneous removal of the access sheath. In this case, a guidewire should be inserted prior to removal of the ureteral access sheath in order to retain access and keep the operating time as short as possible.

The edges of fragments of calcium oxalate monohydrate stones are often sharp, which makes it more difficult to remove them via the access sheath, Therefore, these stones should be fragmented completely. Infection stones often fragment while being pulled through the access sheath. If all visible fragments have apparently been removed from the calyceal system, a final evaluation of the calyceal system is recommended. It is advisable first to look for stone fragments in the upper pole, then in the mid calyx, and lastly in the lower pole. The latter is important because flexible endoscopy of upper urinary tract stone fragments often leads to their migration from the upper to the lower calyx [12].

The aim of endourologic treatment of renal stones is to achieve endoscopically confirmed stone-free status (Figure 39.5).

Large stone burden

Stones exceeding a diameter of 2 cm are difficult to treat. Due to the limited diameter of the ureteral access sheath, the number of stone fragments to be removed will increase with large stones, and a significant increase in operating time has to be accepted. A study by Ober *et al*. compared flexible URS in large stones ($>100\,\mathrm{mm}^2$) to a control group with smaller stones ($<100\,\mathrm{mm}^2$). The operating times were 70 min and 47min, respectively, but stone-free rates were comparable (84.3% and 91.7%, respectively). The main differences were in the retreatment rate (47% and 12%, respectively) and risk for febrile urinary tract infection (17.6% and 4.2%, respectively) (Table 39.5). To evaluate these results, treatment alternatives, such as a minimally invasive PCNL (mini-perc), should also be taken into consideration (Table 39.6).

Diverticular stones

A particular difficulty is the treatment of diverticular stones [13]. The morphologic obstruction caused by the neck of the diverticulum should be treated at the same time in order to prevent stone recurrence (Figure 39.6). If flexible URS is used to treat diverticular stones, it is proposed that the diverticular neck is treated first. In contrast to percutaneous approaches, this has to be done using a holmium laser as otherwise it will not be possible to reach and remove the diverticular stone.

The success of retrograde flexible URS in the treatment of diverticular stones depends on their location in the diverticulum. Unfortunately, a standard intravenous pyelogram (IVP) only shows a two-dimensional aspect of the diverticulum. In practice diverticular stones often are located in a dorsal or ventral calyx, which means that the flexible scope has to manage two deflections in two different directions. This can explain why sometimes the retrograde flexible approach does not reach the diverticular stone.

ESWL does not represent an alternative treatment because, while it will fragment diverticular stones, it has no impact on the morphologic obstruction. The main treatment alternative in the treatment of diverticular stones is a percutaneous approach by means of PCNL. Aguilar *et al*. compared three different treatment modalities in diverticular stones: flexible URS, mini-perc, and a combined approach (Table 39.6), and found success rates of 66.7%, 94.1%, and 77.8%, respectively. Flexible URS is effective in upper pole diverticular stones, whereas mini-perc is more successful in lower pole diverticular stones.

In summary, retrograde flexible URS offers an effective treatment modality in diverticular stones compared to ESWL, but a percutaneous approach to diverticular stones is the most effective treatment modality. Flexible URS has some limitations, , particularly in lower pole diverticular stones [14].

Renal stones in children

Although retrograde endoscopy in children is very common for ureteral stones, there is only limited experience in the primary retrograde treatment of renal stones. To date ESWL is the treatment of choice for calyceal stones in children. However, due to the ability of the infant ureter to pass large stones spontaneously, it is questionable if a primary retrograde approach to renal stones is necessary. In contrast to the limited data for retrograde flexible procedures in children, there is evidence that a percutaneous approach in children with large stone burden is as effective and secure as in adolescence. The future will show if the ongoing miniaturization of flexible scopes will lead to a more significant role for retrograde flexible ureteroscopy in children.

Management of complications

Although flexible URS is easy to learn, there are a few complications that should need to be managed during the procedure. Most of these difficulties have not been reported in the literature and no statistical data for their incidence are available. The main complications with flexible URS are discussed below, together with tips for overcoming them.

Inability to insert a ureteral access sheath

In about 15–20% of all patients scheduled for retrograde flexible URS to treat upper urinary tract calculi, a primary approach to the upper urinary tract by insertion of a ureteral access sheath is not possible. Usually this is not due to a stricture or other pathology of the ureteral orifice. Instead, a muscular spasm of the wall of the ureter inhibits the placement of the ureteral access sheath. Sometimes it is suitable first to dilate the ureter using the inner part of the ureteral access sheath. If this does not work, a double-J stent should be placed and the planned procedure delayed for 3 or 4 days.

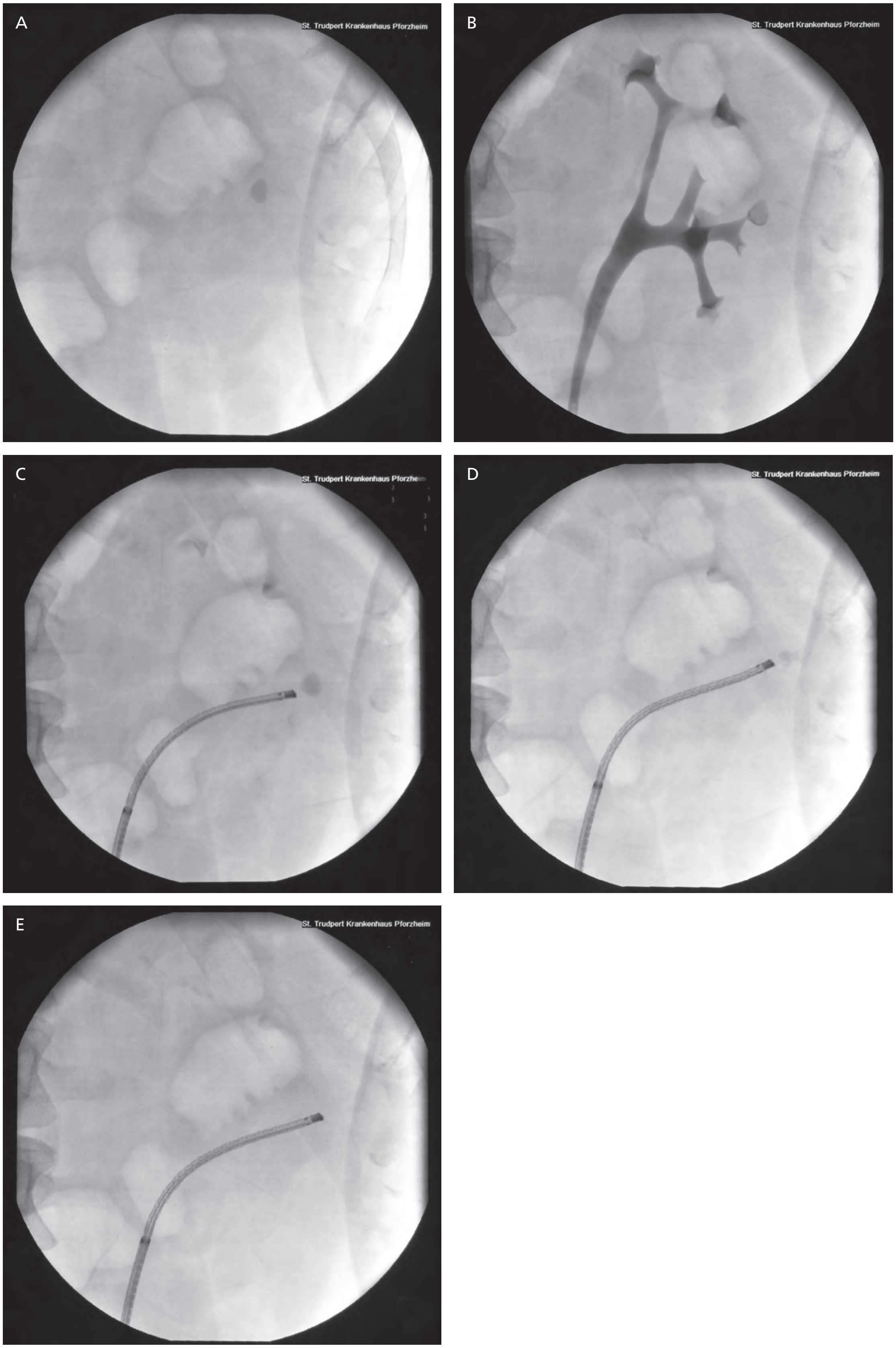
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Figure 39.5 Treatment of a mid calyceal stone by means of retrograde flexible ureterorenoscopy. (A) Radio-opaque stone of the mid calyx with a diameter of 10 mm. (B) Retrograde pyelography of the calyceal system. (C) Flexible scope facing the mid calyceal stone. (D) Fragmented stone after holmium laser lithotripsy. (E) Complete removal of the mid calyceal stone.

Perforation of the ureter

Perforation of the ureter can occur if the ureteral access sheath is placed too forcefully. Another possibility is that the ureteral access sheath was moved forward after the inner part of the access sheath had been removed. Infrequently the cause of the perforation is the flexible scope itself. In case of perforation, it is recommended that a double-J stent and a transurethral catheter are inserted. By creating a low pressure urinary diversion, these perforations will recover without any long-term complications. The main advice to prevent ureteral perforations is to perform the procedure with care and not to force any step of the procedure.

Unfavorable stone position

Sometimes stones are located in unfavorable locations, such as the diverticula, lower poles or calyces with ventral or dorsal position. In all these cases it is recommended first to move the stone to a more favorable position and then to perform fragmentation. The best stone position for further treatment depends on the anatomy of the calyceal system. In many cases, stones should be moved to the mid calyx. If lithotripsy has been started, it is very important to avoid any migration of stone fragments to other parts of the calyceal system, as catching these fragments is very time-consuming and the stone-free rate may be reduced [15–17].

Table 39.5 Results of ureterorenoscopic management in renal calculi with large stone burden in comparison to smaller stone burden.

	Stone burden $< 100\,\text{mm}^2$	Stone burden $> 100\,\text{mm}^2$
Number	393	127
Operating time (min)	47	70
Stone-free rate (%)	91.7	84.8
Retreatment rate (%)	12.0	47.0
Pyelonephritis (%)	4.2	17.6
Perforation (%)	2.5	3.2

Respiratory movement of the kidney

There is significant movement of the kidney with the patient's breathing. In small calyceal stones and narrow renal pelvices particularly, it is recommended that this respiratory movement of the kidney is reduced in collaboration with the anesthesiologist, who can stop the respiration for several minutes in order to facilitate stone removal. This collaboration illustrates how the maximum success in endourology can only be achieved with a team consisting of surgeon, nurse, and anesthesiologist.

Impacted stone inside a tipless basket

A calyceal stone that has been successfully caught may be too large to be extracted, but cannot be removed from the tipless basket. In these cases a holmium laser can be used to cut one of the wires of the tipless basket. In future new hand grips will be available to disconnect and reconnect the tipless basket.

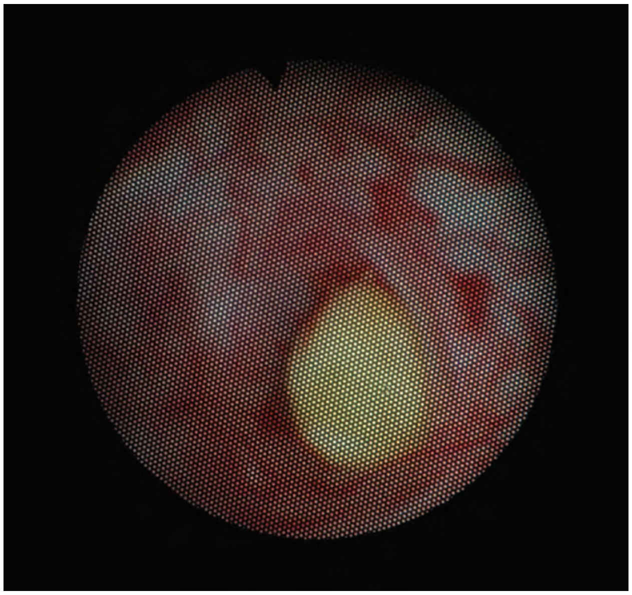

Figure 39.6 Endoscopic view of a diverticular stone. The diverticular neck has not been incised and only the distal tip of the stone is visible.

Table 39.6 Results of ureterorenoscopic management of renal diverticular stones in comparison to mini-perc and combined approach.

Group	Total number	Upper pole diverticulum (n)	Mid calyx diverticulum (n)	Lower pole diverticulum (n)	Stone-free rate (%)
Flexible ureterorenoscopy	6	4	0	2	66.7
Mini-perc	17	1	5	7	94.1
Combined approach	9	4	3	1	77.8

Breakage of laser fibers

There are only rare reports in the literature dealing with the management of broken laser fibers, but all experienced endourologic surgeons know about this problem. As lost fragments of the laser fiber can cause stone recurrence, it is recommended that these fragments are caught immediately using disposable forceps, such as the "Graspit." Tipless baskets are not effective as they will catch the laser fiber fragment across the tipless basket.

Adjuvant shock-wave lithotripsy

Sometimes it is advisable to combine ESWL with retrograde flexible URS. The few studies that have evaluated this approach suggest it is beneficial for large peripheral stone burden that cannot easily be reached by retrograde flexible URS alone [18, 19]. After fragmentation of the calyceal stone, smaller fragments can be removed by means of flexible URS in a second session. This combination treatment may be one of the most important indications for ESWL in the future [18, 19].

Treatment alternatives to flexible ureterorenoscopy

The effectiveness of flexible URS can only be evaluated if compared to other treatment alternatives. From the endourologic standpoint, mini-perc is the main treatment alternative to retrograde flexible URS. A short overview of the differences between these treatments is given below (Table 39.7).

Table 39.7 Comparison of the main characteristics of retrograde flexible ureterorenoscopy to minimally invasive percutaneous nephrolithotomy in the treatment of renal calculi.

	Flexible ureterorenoscopy	Percutaneous approach (PCNL)
Approach	Easy to perform, if access sheath is used	Requires experience
Stone-free rate	High	Higher
Lithotripsy	Holmium laser	Holmium laser Ballistic lithotripsy Ultrasound lithotripsy
Treatment if hemostasis is altered	Decision on an individual basis possible	Impossible
Best stone localization	Upper calyx Mid calyx	Lower calyx
Best stone size	<2 cm	>2 cm
Costs	High	Moderate

PCNL, percutaneous nephrolithotomy.

Access to upper urinary tract

Flexible URS is an easy to perform if suitable disposables, such as ureteral access sheaths, are used. Even for beginners with no particular endourogic expertise, the insertion of a ureteral access sheath and the approach to the upper urinary can be learned quickly. In contrast, percutaneous techniques require a long learning curve.

Stone-free rate

Flexible scopes offer an enhanced stone-free rate in renal calculi in comparison to ESWL, but in comparison to percutaneous procedures, flexible URS gives a lower stone-free rate. Therefore, the decision about the endourologic procedure should be based on localization and size of stone. Solitary small stones in the upper or mid calyx in particular are very suitable for retrograde flexible URS. Stones in the lower calyx, particularly larger stones, are more suitable for a primary percutaneous approach [20, 21].

Lithotripsy

Holmium laser lithotripsy is required with retrograde flexible URS. The small caliber of the working channel requires small laser probes. Ultrasound or ballistic lithotripsy are not possible in flexible URS. If percutaneous techniques are performed, holmium laser, ballistic, and ultrasound probes for stone fragmentation can be used. As ultrasound and ballistic lithotripsy are more cost-effective methods, a percutaneous approach is associated with lower costs compared to flexible URS.

Hemostasis

Flexible URS can be performed in patients with mild alteration of hemostasis, such as those on warfarin and Aspirin, although the decision to treat must be made on an individual basis. Percutaneous procedures in such patients are contraindicated [22, 23].

Technical equipment

When comparing flexible ureterenoscopy to percutaneous techniques, it is important to remember that the former is a high cost procedure because flexible scopes for the upper urinary tract are expensive to purchase and repair. They are fragile and in inexperienced hands may be damaged easily. Percutaneous scopes are cheaper and more robust. The maintenance and sterilization process for flexible scopes is complicated due to their length and fragility, whereas rigid percutaneous scopes can easily be maintained and sterilized.

Limitations due to the morphology of the calyceal system

There are certain limitations to flexible URS in the upper urinary tract. Sometimes a long calyceal neck makes it impossible to enter a calyx, particularly lower calyces, and in these cases a percutaneous approach is more successful. Flexible retrograde and percutaneous approaches complement each other in these cases, and only the availability of both these techniques will offer the maximum success in endourologic treatment of renal calculi. Whether double-bending flexible ureterorenoscopes can play an important role in reaching outlying parts of the calyceal system is questionable [24–26].

Cost of treatment

One of the most important ongoing discussions in retrograde flexible URS concerns cost. As mentioned above, flexible scopes are very complicated and fragile instruments, and the deflection mechanism is easily damaged. The sterilization process is also very complex, due to the length of the flexible scope and the small caliber of the working channel. The distal tip of the working channel, manufactured from a plastic material that allows deflection of the instrument, is susceptible to alterations, which cause additional repair costs.

The durability of flexible scopes depends on the experience of the surgeon and staff involved in the sterilization process. In experienced hands the durability of a flexible scope is up to 50 procedures, in inexperienced hands only 5–10 procedures. In a study of 630 interventions using flexible scopes, the mean durability was 21 interventions. The average repair cost per procedure in 2009 was about €155 (c. US$215).

Flexible ureterenoscopy also carries additional costs due to the use of disposables, guidewires, ureteral access sheaths, tipless baskets, and ureteral stents.

Against these higher costs in comparison to other treatment alternatives, such as ESWL, the reduced treatment time for flexible URS should be considered. The reduced cost associated with this will vary from country to country, and also depend on national reimbursement systems. As such the cost-effectiveness of flexible URS will depend on the country in which a surgeon is practicing [27–30].

Antegrade flexible ureterorensocopy

So far only retrograde flexible URS had been discussed. In cases, where an additional percutaneous approach to the kidney is necessary, flexible scopes can be used to perform antegrade flexible ureteroscopy. By combining minimally invasive percutaneous procedures with antegrade and retrograde flexible ureteroscopies, almost all parts of the urinary tract can be reached. In order to achieve maximum success with flexible URS, antegrade access to the ureter should be considered. With an antegrade approach, a ureteral access sheath can be placed via a guidewire using the percutaneous access. Antegrade flexible URS is as easy to perform as the retrograde version, even in children [31].

Flexible ureterorenoscopy in anomalous kidneys (see also Chapters 61 and 62)

ESWL and percutaneous procedures are associated with particular difficulties in patients with anomalous kidneys with stones. Stone clearance after ESWL is poor and percutaneous access to the kidney is sometimes impossible. By means of retrograde flexible URS, renal calyceal stones can often be removed more easily. However, there have been only limited reported cases of this technique in anomalous kidneys [32].

Conclusions

URS management of renal calculi is a highly effective, reliable, and safe treatment modality, which should be offered to stone patients as a treatment alternative to ESWL. However, as flexible URS as a primary approach to renal calculi is not included among the general recommendations in international guidelines, it should only be performed with the explicit consent of patients. Using ureteral access sheaths and once sufficient experience in flexible URS has been acquired, renal calculi can easily be treated endoscopically. Retrograde flexible URS is not suitable if renal stones exceed 2 cm in diameter. In these cases a percutaneous approach by mini-perc is preferred from an endourologic point of view [33].

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CHAPTER 40

Diagnostic Ureteroscopy

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Introduction

Perhaps nowhere else have the improvements in ureteroscopic instrumentation had such a significant effect on treating patients than in diagnostic ureteroscopy. In the past, urologists were at the mercy of radiologic imaging capabilities to evaluate the upper urinary tracts of our patients. Computed tomography, angiography, and retrograde studies were the only tools available for evaluating patients with possible upper urinary tract abnormalities. With the development of safe and effective ureteroscopy, urologists need no longer rely on these radiologic imaging studies alone. Ureteroscopy has allowed us to better determine the underlying cause of bleeding in patients with benign essential hematuria, and has greatly improved our ability to treat these patients.

The first ureteroscopes to be developed were limited to diagnostic use because they lacked a working channel. These prototypical ureteroscopes had only visual and illuminating capabilities [1, 2]. As ureteroscopes rapidly improved with the development of working channels and deflection capabilities, their therapeutic role in treating upper urinary tract abnormalities, particularly urolithiasis, expanded greatly. Although these therapeutic indications dominate the use of ureteroscopes, the addition of working channels and deflection also improved their diagnostic capabilities. It is now possible to completely inspect the intrarenal collecting system, and through the working channel sample fluid for cytology and pass biopsy forceps to sample any abnormal tissue identified. The use of ureteroscopy as a diagnostic tool will grow as ureteroscopes continue to improve their imaging abilities, maneuverability, and durability. The diameter of ureteroscopes has decreased over the years of development, which greatly increases our ability to perform ureteroscopy without prior ureteral dilation, allowing clearer inspection of the untouched ureteral urothelium [3]. As the invasiveness of ureteroscopy decreases, there will be little reason to rely on radiologic studies alone when the urothelium of the upper urinary tract can be safely inspected and sampled.

This chapter will discuss the diagnostic uses of ureteroscopy, the specific technical nuances of diagnostic ureteroscopy, and current results of ureteroscopy for evaluating hematuria.

Indications

Ureteroscopy can be used diagnostically to investigate any condition that may involve the upper urinary tract. Ureteroscopy allows urologists direct visualization, fluid sampling, and tissue sampling of the upper urinary tract. Any evaluation for conditions that might benefit from these diagnostic interventions should be considered for ureteroscopy. Common indications for diagnostic ureteroscopy include evaluating patients with unexplained recurrent or persistent urinary tract infections, persistent positive cytologies, upper urinary tract filling defects, and hematuria [4, 5]. Ureteroscopic evaluation of filling defects and hematuria are discussed below.

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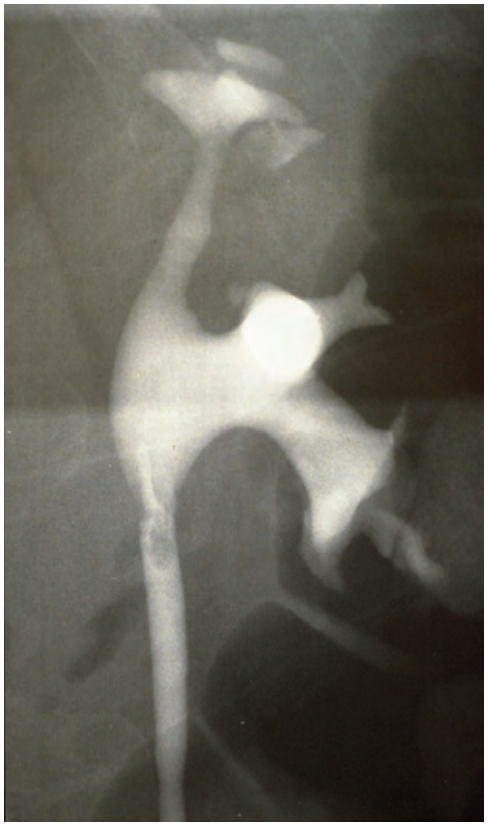

Figure 40.1 Small filling defect, ureteropelvic junction.

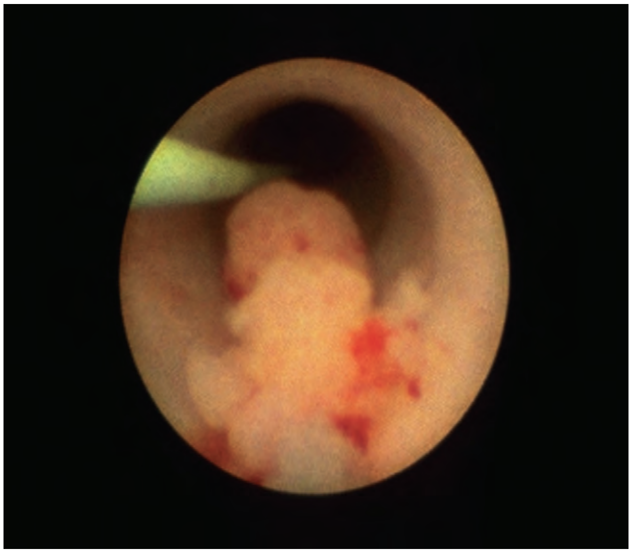

Figure 40.2 Papillary, low-grade tumor.

Upper urinary tract filling defects

Excretory urography is the most common imaging modality for evaluating patients with hematuria. Other upper urinary tract imaging studies evaluating patients with hematuria include renal sonography and computed tomography (CT) urography. Expanded use of CT urography with its ability to better identify radiolucent stones and better define soft tissue defects has decreased but not eliminated the need for diagnostic ureteroscopy evaluating filling defects. Despite improvements in upper urinary tract imaging for patients with hematuria, the evaluation of the upper urinary tract filling defects identified on imaging studies remains one of the most common indications for diagnostic ureteroscopy.

Filling defects may include calculi, transitional cell carcinoma (TCC), blood clots, benign tumor (e.g. fibroepithelial polyps), extrinsic compression (e.g. crossing vessels), and intrinsic ureteral strictures or ureteropelvic junction (UPJ) obstructions (Figure 40.1) [4].

Direct ureteroscopic inspection alone often provides the diagnosis when evaluating upper urinary tract filling defects [4]. Upper urinary tract calculi are easily distinguishable from soft tissue lesions, and treatment can be rendered using a holmium laser in the same setting. Extrinsic filling defects can often be determined visually with the appearance of compression of the ureter in the absence of any intrinsic mass in the ureteral lumen. When the ureter is extrinsically compressed by a venous structure, the ureteral lumen is distensible during ureteroscopic inspection, whereas extrinsic compression from an artery often results in visible pulsations. Ureteral strictures and UPJ obstructions also may be visually confirmed.

With the expanded use of CT urography, most upper urinary tract calculi can be identified before ureteroscopy. In this setting, most filling defects will be soft tissue in nature and should be considered cancer until proven otherwise. The ureteroscopic appearance of upper tract TCC is similar to the more familiar cystoscopic appearance of bladder-based TCC. Low-grade urothelial tumors have a typical papillary, frondular appearance (Figure 40.2). Higher grade tumors can be more sessile and at times appear necrotic (Figure 40.3). Fibroepithelial polyps, while often long and papillary, can be distinguished from upper urinary tract TCC as they frequently have a smooth, normal-appearing urothelial surface.

Although upper urinary tract TCC can often be determined by direct ureteroscopic inspection alone, this should not be the sole basis of its diagnosis. When evaluating any soft tissue lesion with concern for possible urothelial cancer, the diagnosis should be based on visual appearance, cytologic evaluation, and biopsy [6].

Treatment of upper urinary tract TCC depends on the location, size, and number of lesions. The most critical factors in deciding the course of treatment are the stage and grade of the tumor. Accurate staging of upper urinary tract TCC can be difficult. CT scanning alone

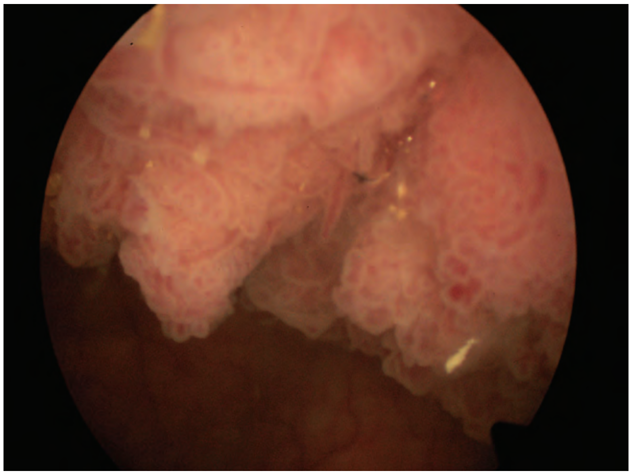

Figure 40.3 Sessile, larger, high-grade tumor with calcifications.

has been shown to be inadequate for accurate staging, and the underlying ureteral musculature can seldom be safely sampled ureteroscopically. Fortunately, stage and grade correlate closely, and accurate grading of the tumor is heavily relied upon to guide treatment options [7]. Cytology and biopsy are complementary tools in diagnosing and grading these tumors. While cytology is specific, it is less sensitive because most low-grade lesions will be missed. Higher grade TCC lesions are more likely to provide positive cytologic findings as the tumor cells have lost their cell–cell adhesion capabilities and demonstrate more easily identifiable morphologic changes. Direct ureteroscopic biopsy is highly sensitive but less specific. Thus, fluid aspirations for cytology and biopsies should be obtained from any suspicious lesion during ureteroscopy. A more extensive description of tissue sampling techniques is given in Chapter 41.

Benign essential hematuria

Evaluating patients with hematuria is one of the most common consultations for urologists. Hematuria initially can be divided into glomerular or nonglomerular causes based on urinalysis alone. Dysmorphic red blood cells, proteinuria, and red blood cell casts would indicate a probable glomerular cause of the hematuria and the patient should be referred to a nephrologist for evaluation and treatment. Nonglomerular hematuria can be caused by urologic problems such as tumors, stones, and urinary tract infections. Most causes of nonglomerular hematuria are determined with a standard hematuria evaluation, which includes upper urinary tract imaging and cystoscopy. If the hematuria evaluation is negative, additional studies might include complete blood count (CBC), coagulation studies, and platelet function studies to rule out bleeding diathesis. Referral to hematology for definitive evaluation can be done if bleeding diathesis is strongly suspected. A urine sample also should be sent for cytology and culture. If an obvious source of the hematuria cannot be determined through conventional studies, the condition is referred to as *benign essential hematuria* [5, 8].

Patients with benign essential hematuria can have frequent bouts of gross hematuria with clots and renal colic; otherwise, their long-term course is generally benign. Some will require repeated transfusions. Benign essential hematuria is found equally in men and women. Additional radiologic studies are frequently done to evaluate patients with benign essential hematuria. Renal arteriography and venography, and magnetic resonance imaging (MRI) arteriography may reveal larger vascular lesions. However, if the patient has already had a quality CT urogram, it is unlikely that a significant vascular lesion will have been missed. These additional imaging studies are usually of low yield because the most common vascular lesions causing benign essential hematuria are small venous abnormalities and hemangiomas [9]. These are seen better on endoscopic inspection of the upper urinary tract and will usually be missed on vascular imaging studies.

Other causes of chronic hematuria, including loin pain hematuria syndrome and the Nutcracker syndrome, should be considered [10–12]. Loin pain hematuria syndrome patients have intermittent pain and microscopic or gross hematuria. Although this diagnostic entity somewhat overlaps benign essential hematuria, loin pain hematuria syndrome has no specific anatomic findings and a significant psychiatric component, specifically associated with somatoform disorder. The Nutcracker syndrome is another potential cause of chronic hematuria. It is caused by venous hypertension of the left kidney due to compression of the left renal vein, between the aorta and the superior mesenteric artery [13]. It also has been described in patients with retroaortic left renal veins. Diagnosis is generally made by demonstrating venous hypertension during venography studies with a pressure drop beyond the point of compression of the left renal vein. Treatment is surgical, with repositioning of the left renal vein or renal autotransplantation.

In the past, some patients with benign essential hematuria required treatment with partial or total nephrectomy. With the advent of current flexible ureteroscopic instruments and techniques, most of these patients can be evaluated and successfully treated ureteroscopically.

The two most common ureteroscopic findings are renal hemangioma and venous abnormalities of the calyces ("minute venous ruptures"). Virchow was the first to describe renal hemangiomas during autopsy studies in 1867, suggesting they may be a cause of chronic hematuria [8]. Rare reports of renal hemangiomas causing unexplained hematuria were published over the next century. Renal hemangioma can be large but are typically quite small, and most commonly occur on the tips of the renal papilla. They may be seen as small red or blue spots, or larger mulberry-like lesions. They are equally distributed between men and women, the right and left kidneys, and the upper and lower poles of the kidney.

Anatomic studies in the past have demonstrated a close anatomic association between the tributaries of the renal vein and the calyceal fornix. These venous sinuses are close to the surface at the calyceal fornix and may erode or rupture through the urothelium [14]. It has been postulated that these venous calyceal fistulas develop following periods of elevated pressure within the intrarenal collecting system [8]. They may be localized or diffuse, and have been described as venous ruptures, varices, renal forniceal hemorrhages, pyelovenous fistula, and hemorrhagic papillitis. They are among the more common causes of bleeding in patients with benign essential hematuria. Usually, these lesions are found in the kidney, rarely the ureter, and are equally distributed between men and women, right and left kidneys, and upper and lower poles. Ureteroscopic evaluation and treatment are more successful when the patient is actively bleeding, and when the lesions are discrete rather than diffuse.

A small number of patients evaluated ureteroscopically for hematuria will be found to have a TCC tumor or calculus. In other patients, nothing will be found. Despite no bleeding lesion being found, most studies report successful resolution of the hematuria after ureteroscopy. It has been suggested this could be due to resolution of unseen venous–calyceal communication because of increased intraluminal pressure during the ureteroscopy [16, 21].

Results with ureteroscopy for the evaluation and treatment of benign essential hematuria are presented in Table 40.1 [16–23]. Overall, the success rate for patients being treated ureteroscopically for benign essential hematuria is 90%.

Technique

The primary goal of diagnostic ureteroscopy is to obtain unhindered visual inspection of the entire upper urinary tract. There are some technical nuances that will help achieve this goal.

Some authors have reported performing flexible ureteroscopy without a working or a safety guidewire. This is possible with some newer flexible ureteroscopes that can be introduced into the ureteral orifice under direct vision without the use of a working guidewire [24]. This technique requires significant expertise and it is not possible with all flexible ureteroscopes in all patients. This technique may soon be the ideal “no touch” method for diagnostic ureteroscopy, and may become less challenging with future generations of ureteroscopes. However, at this time it is limited to certain ureteroscopes in the hands of experienced endourologists. For these reasons, we recommend and will review the standard technique of diagnostic ureteroscopy using rigid and flexible ureteroscopy to inspect the entire upper urinary tract (Table 40.2).

Bleeding from the urinary tract can occur anywhere from the upper pole of the kidney to the urethral meatus. Endoscopic evaluation of these patients begins with careful urethroscopy. Special attention is paid to the prostatic urethra, which can be a frequent site of benign gross hematuria. The bladder urothelium is carefully and completely inspected, and a bladder lavage for cytology is performed. The next cystoscopic step is careful inspection for bloody efflux from the ureteral orifices. When gross hematuria is present, this critical step will allow differentiation of unilateral and bilateral hematuria. Bilateral gross hematuria is typically “nonurologic” and a ureteroscopic evaluation likely will not be helpful.

Rigid and flexible ureteroscopy provide complementary access to the upper urinary tract [1]. While rigid ureteroscopy allows direct insertion and easy control of the ureteroscope, it does not allow easy access to the ureter superior to the iliac vessels. Without the ability to deflect the tip of a rigid ureteroscope, inspection of the intrarenal collecting system is impossible. Flexible ureteroscopy provides complete access of the entire intrarenal collecting system and upper ureter. However, inspection of the distal ureter is difficult because of buckling of the ureteroscope into the bladder. For this reason, rigid ureteroscopy is performed below the iliac vessels, and flexible ureteroscopy above. This combination of rigid and flexible ureteroscopy provides complete visual inspection of the entire upper urinary tract.

When performing ureteroscopy for the evaluation of hematuria, tumor surveillance, or other diagnostic purposes, it is important to recognize that the standard ureteroscopy technique can produce traumatic lesions that may be mistaken for pathology. Care should be taken to minimize this trauma to the ureter during ureteroscopy, as it will interfere with the diagnostic visual inspection. The effort to minimize trauma begins with using the smallest ureteroscope practical to avoid the need for dilation. Direct insertion of a rigid ureteroscope without prior dilation of the intramural ureter allows clean inspection of the distal ureteral mucosa. Avoiding the use of a guidewire during direct insertion of the rigid ureteroscope will further minimize trauma to the ureter.

The ureter is inspected with the rigid ureteroscope from the ureteral orifice to the ureter at the level of the

Table 40.1 Results with ureteroscopy for hematuria.

			Endoscopic findings						Success (i.e. no recurrence) (%)			
Study		Number	Hemangioma	Other discrete lesions	Diffuse lesions	Tumor	Stone	Nothing	Discrete lesions	Diffuse lesions	Total	Follow-up (months)
Kavoussi *et al*. 1989 [15]		8									5/6 (83%)	11
Bagley *et al*. 1990 [16]		32	11	2	4	1	1	5	11/12 (92%)	0/4 (0%)	11/16 (69%)	
Kumon *et al*. 1990 [17]		12	4	5	1			2			9/9 (100%)	10.3
Nakada *et al*. 1997 [18]		17	5	5	2	1	1	3	9/11(82%)	0/3 (0%)	9/14 (64%)	60
Tawfiek *et al*. 1998 [19]		23	7			3	2	5	11/11 (100%)		21/22 (95%)	8
Daneshmand	2002	15	15		6 (hemangiomas)						11/12 (92%)	20.2
Mugiya	2007	23	2	14			2	5	16/16 (100%)		23/23 (100%)	73
Brito	2009	13	9	4	3 (hemagiomas)				10/10(100%)	3/3 (100%)	13/13 (100%)	26
Mugiya	2010	20	4	15				1	19/19 (100%		20/20 (100%)	16
Total 163			57 (35%)	45	16		6	21 (13%)	76/79 (96%)	3/10 (30%)	122/135 (90%)	

Table 40.2 Technique of diagnostic ureteroscopy.

Cystourethroscopy
Careful and complete
30° and 70° lens
Bladder lavage for cytology
Visualize ureteral efflux
Localize gross hematuria when present
Remove cystoscope
Rigid ureteroscopy
Direct insertion of ureteroscope without a wire
Leave wire through the ureteroscope to the level inspected
Remove rigid ureteroscope
Flexible ureteroscopy
Over the previously placed wire
Inspect proximally from the level reached with rigid ureteroscope
Systematic inspection of intrarenal collecting system
Aspirate intrarenal urine for cytology
Biopsy any suspicious lesions
Lavage for cytology after biopsy
Fulgurate any bleeding lesion
Remove flexible ureteroscope and stent as indicated

iliac vessels. Care is taken to avoid excessive irrigation. Just enough irrigation is used to provide adequate distention of the ureter for visualization while preventing over-distention of the ureter and intrarenal collecting system. Even minimal over-distention of the collecting system can lead to small areas of urothelial hemorrhage and render the remaining inspection of the ureter for true sources of bleeding pointless.

Once the distal ureter is completely inspected to the level of the iliac vessels, further inspection of the proximal ureter requires flexible ureteroscopy. A guidewire is passed through the rigid ureteroscope, only as high as necessary into the ureter to allow placement of the flexible ureteroscope. Preferably, the guidewire is passed only to the level of the ureter that has been inspected with the rigid ureteroscope. The rigid ureteroscope is removed, leaving the guidewire in place, and the flexible ureteroscope is passed over this guidewire to the proximal extent of rigid ureteroscopic inspection. Flexible ureteroscopic inspection is then performed from this point and proceeds proximally in a retrograde fashion, generally without a safety guidewire. Again, this is to avoid trauma to the ureteral urothelium that might interfere with the diagnostic inspection. When using this technique of diagnostic ureteroscopy, a urothelium is being inspected that is “untouched” either by guidewires or ureteroscopes.

When inspecting the intrarenal collecting system, completeness is ensured with a systematic approach using combined endoscopic and fluoroscopic imaging. Irrigation with a dilute contrast mixed in normal saline allows precise documentation and navigation throughout the intrarenal collecting system. The intrarenal collecting system is inspected from the upper pole, moving systematically through the calyces to the lower pole, and each calyceal inspection is documented fluoroscopically. Care should be taken to avoid over-distention of the intrarenal collecting system to minimize urothelial trauma. Benign essential hematuria can be caused by small, subtle urothelial lesions. Any trauma from the guidewire, over-distention, or ureteroscope can prevent accurate visualization of these lesions. Likewise, prestenting should be avoided to prevent stent-related inflammation of the urothelium, which also will prevent accurate inspection of the upper urinary tract. A nontraumatic approach to diagnostic ureteroscopy is essential.

Ureteroscopy is truly an endoscopic extension of cystoscopic principles to the upper urinary tract. Ureteroscopic inspection of the upper urinary tract allows direct visualization and recognition of pathologic lesions, just as cystoscopy allows visual recognition of calculi, neoplasms, and other urothelial lesions. Visual inspection of the upper urinary tract via endoscopy permits visual recognition and differentiation of upper urinary tract pathology. TCC generally has an easily distinguishable appearance. However, some lesions, such as high-grade TCC, may be difficult to distinguish from benign soft tissue lesions such as inflammation. Ureteroscopic sampling for cytologic and pathologic analysis greatly improves our ability to distinguish malignant from benign soft tissue lesions. Direct irrigation through the ureteroscope with normal saline and aspiration for cytology is done whenever there is the possibility of a malignant lesion. Direct, precise biopsy, guided by ureteroscopic visualization of the lesion, permits a more accurate diagnosis than a brush biopsy guided by fluoroscopy alone. Biopsy of any suspicious lesions can be performed with 3F biopsy forceps for sessile lesions, or flat wire baskets for papillary lesions [6].

When treating patients with benign essential hematuria, when a source of bleeding is found, it should be fulgurated. This can be performed with either electrocautery delivered with a 2F blunt tip electrode (30–40 W coagulating current), or the neodymium:YAG laser. The holmium:YAG laser can be used, but at a wavelength of 2100 nm the laser energy is highly absorbed in water, resulting in relatively shallow tissue penetration of 0.4 mm. The holmium:YAG laser is primarily ablative, whereas the neodymium:YAG laser is more coagulative with a tissue penetration of 4–6 mm.

Conclusions

Improvements in the techniques and instrumentation of ureteroscopy have dramatically improved the ability to evaluate and treat patients with upper urinary tract abnormalities, including those who present with filling defects or benign essential hematuria. The entire upper urinary tract can be safely and reliably inspected endoscopically. Conditions such as renal hemangioma that may have resulted in a nephrectomy in the past are now better understood and treated in a renal-preserving minimally invasive manner thanks to these improvements in ureteroscopy. The future of diagnostic ureteroscopy is bright, and will likely continue to expand as ureteroscopes, tissue sampling methods, and methods of intervention incrementally improve.

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CHAPTER 41

Ureteroscopic Diagnosis and Treatment of Upper Urinary Tract Neoplasms

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Introduction

Ureteroscopy is a major technique in the diagnosis, treatment, and surveillance of upper tract neoplasms. The introduction of fiberoptic illumination and imaging, and small rigid and flexible ureteroscopes, which were developed in the early 1980s, have made access to the entire upper collecting system routine. Combined with devices for tissue sampling and then tissue ablation, accurate diagnosis and treatment is possible. Other diagnostic studies, including radiologic, cytologic, and molecular techniques, can provide initial or supportive diagnostic information, yet remain secondary to endoscopy as the definitive study.

Upper tract neoplasms are relatively rare. Transitional cell carcinomas (TCCs) in the ureter and intrarenal collecting system account for approximately 5% of all TCCs [1]. They are, however, more common in patients with a previous history of carcinoma of the bladder [2, 3]. The presentation may be different in those with and without a history of bladder cancer. In those with no history of bladder cancer, the most common presentation (80%) is with hematuria, either gross or microscopic [1, 4, 5]. The lesion may be an incidental finding in 10–15% of patients, but flank pain can be seen in up to 30% of patients. Physical findings are rarely present unless the patient has metastatic tumor, unusual masses, or hydronephrosis secondary to obstruction.

Radical nephroureterectomy with removal of a bladder cuff has been considered the standard for treatment of upper tract tumors [6]. The application of endoscopic techniques to these lesions, initially in patients with a solitary kidney or compromised contralateral kidney, which have been considered imperative indications, has shown the feasibility of this treatment. Consequently, it has been performed increasingly in patients with a normal contralateral kidney [7, 8]. Evidence of progressive functional renal loss in patients undergoing nephrectomy for renal cell carcinoma can also be expected in patients losing their kidney to nephroureterectomy, and is a stimulus for nephron-sparing surgery [9].

Noninvasive diagnosis

Radiologic studies, including intravenous contrast studies to outline the collecting system, along with excretory urography or computed tomographic (CT) urography are the most useful noninvasive diagnostic techniques. A filling defect is the most common finding and may indicate an upper tract urothelial neoplasm. The differential diagnosis includes blood clot, lucent calculus, air bubble, fungal ball, sloughed papilla, external compression with a crossing vessel, or benign inflammatory or neoplastic lesion. One series using a multidetector CT scanner for CT urography in patients with gross hematuria demonstrated a very high sensitivity, specificity, and accuracy [10]. In some patients with a severe contrast allergy with nonvisualization of the collecting system, retrograde ureteropyelography may be indicated. However, this suffers from a low accuracy [4, 11].

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Renal ultrasound can define intrarenal calculi or hydronephrosis accurately and renal masses can also be demonstrated, but ultrasound is less useful to define small intraluminal soft tissue masses.

CT can be more helpful. It can accurately distinguish calculi from soft tissue masses. It is also helpful in demonstrating masses extending beyond the collecting system or enlarged lymph nodes. Inclusion of a pyelographic phase with reconstruction of the excretory system or an abdominal radiograph taken after the administration of contrast as an anteroposterior ureteropyelogram may be most useful in demonstrating intraluminal lesions [10, 12].

Magnetic resonance imaging (MRI) has similar limitations, especially in the cross-sectional mode [13]. The magnetic resonance urogram (MRU), designed to image the fluid of a distended collecting system, may be helpful in some patients with nonfunctioning kidneys or severe contrast allergies.

Cytologic study of voided urinary samples is of limited value because of the frequent equivocal and false-negative findings. It can be useful in detecting high-grade tumors which shed obviously malignant cells in the urine. The sensitivity of voided urinary cytology increases with an increasing grade of neoplasm, ranging from 11% for grade I to 83% for grade IV lesions [14]. Elective ureteral catheterization for a specific and localized upper urinary tract sample for cytologic study is occasionally indicated in patients with positive cytology without radiographic findings and with normal cystoscopy and bladder biopsy. However, routine ureteral catheterization to collect urine from a radiographically abnormal area is no longer indicated if ureteroscopy can be performed. Similarly, fluoroscopic-guided brush biopsy is rarely indicated when ureteroscopy is available.

One of the newest studies available is fluorescence *in situ* hybridization (FISH) of voided urine. The technique was first described for detecting bladder tumors and has variably been shown to be of value or unhelpful. Studies of voided urine to detect upper tract TCC have shown sensitivities higher than voided cytology, with similar or slightly lower specificity [15–17]. Ongoing studies suggest that there may be greater accuracy when the upper tract is sampled directly.

Endoscopic diagnostic techniques

Endoscopic evaluation of an abnormality in the upper urinary tract suspicious for a neoplasm includes inspection of the entire bladder and involved collecting system. Cystoscopic inspection of the bladder is an essential component in the evaluation of the patient with hematuria and/or filling defects because of the high risk of associated bladder tumors. It also provides access to the ureter for retrograde pyelography and for ureteral endoscopy. The upper tract is then studied after complete inspection of the bladder with biopsy of any suspicious lesions. A retrograde ureteropyelogram may give more information regarding the extent of the filling defect, suspicious lesion, or ureteral abnormalities that might affect access for treatment. A cone-tipped retrograde injection most efficiently outlines the entire collecting system without traumatizing the ureter itself. It may be necessary to use multiple injections of different concentrations of contrast with multiple radiographic views to define the extent of the lesion fully. Care should be used to prevent over-filling of the collecting system or overly dense radio-opacity, which can obscure filling defects. Initial ureteral catheterization without contrast study should be avoided since it can traumatize the specific lesion of interest and the otherwise normal ureteral mucosa.

A “no touch technique” should be employed to examine the involved upper collecting system. The distal ureter is first inspected either with a small rigid endoscope, preferably one small enough to pass into the orifice without other dilation, or with a flexible ureteroscope that can be passed into the ureter without dilation [18]. In this way, the ureter can be inspected without prior instrument trauma. When using a rigid scope, it is passed as far as possible into the lumen. In a young muscular male, the rigid endoscope can usually be passed throughout the distal third of the ureter, while in an older female it may pass easily to the level of the renal pelvis. A guidewire is then left in place as the endoscope is removed, passed only to the level of the ureter that has been inspected with a rigid scope. It should not be passed into the intrarenal collecting system as the tip of the wire can traumatize the calyx or the renal pelvis and obscure subsequent visual inspection. The smallest flexible ureteroscope is then passed over the guidewire into the ureter. If a small flexible ureteroscope can be passed directly into the ureter, the steps of rigid ureteroscopy and wire placement can be avoided.

The flexible ureteroscope is used to inspect the more proximal portions of the ureter not previously seen and the intrarenal collecting system. Inspection at that level should be systematic, going from the renal pelvis to the upper infundibula and calyces, and then to the mid and then the lower pole. In this way the risk of trauma to the mucosa with the endoscope is minimized.

Continuous irrigation with saline is maintained through the working channel of the ureteroscope to clear the field of view. Iodinated contrast can be used in the irrigant to outline the collecting system for fluoroscopic monitoring. Positioning of the flexible ureteroscope throughout the collecting system can then be confirmed fluoroscopically. Care must be taken to avoid overfilling the collecting system, since this can induce submucosal hemorrhage and rupture of the fornices. When adding contrast through the endoscope within the collecting system, the irrigant present should be removed. Lines of refraction will be visible as fluids of two different densities mix. This can be avoided by minimizing the mixing.

If there is a specific lesion to be examined, such as a filling defect or a point of obstruction, then the distal portion of the urinary tract should be inspected first, followed by the lesion itself in order to inspect it within a clear visual field without other manipulation that may cause bleeding and obscure the field of view. In many cases, visual inspection alone can provide a diagnosis [19–22]. For example, the appearance of a calculus will readily distinguish it from a low-grade papillary tumor. An extrinsic mass can also be readily distinguished. A vascular impression on the renal pelvis will become more prominent as the pelvis is emptied and less prominent as it fills. In addition, an arterial impression can be seen pulsating. In each case, irrigant with contrast should be used so that fluoroscopy can demonstrate the tip of the ureteroscope at the filling defect. In this way, correct visualization and identification of the lesion can be confirmed.

Epithelial neoplasms may have totally different appearances. Low-grade TCCs have a typical papillary appearance, similar to the same lesions in the bladder (see Videos 41.1, 41,2A,C, and 41.3). High-grade TCCs may be more sessile and less papillary, often with necrotic or inflammatory debris on the surface. However, these differences are not consistent. El-Hakim *et al*. found an accuracy of only 70% in determining the grade of an upper tract neoplasm from appearance alone [23].

Benign lesions can also be diagnosed endoscopically but without perfect accuracy. Fibroepithelial polyps located within the pelvis and inverted papillomas throughout the upper collecting system have been seen to have a smooth, rounded surface [24]. The appearance may give an impression of an intact epithelial layer. These features have not been prominent enough to allow visual identification, but they are strongly suggestive. All observed benign lesions, including fibroepithelial polyps, inverted papillomas, and hemangiomas located in the ureter or the ureteropelvic junction (UPJ) can be narrow, elongated, and worm-like.

In some specific instances, visual inspection alone may not be adequate to diagnose a neoplasm. High-grade urothelial neoplasms can be confused with inflammatory lesions or may be obscured by tumor growing submucosally or proximal to obstructive edema. There may be calculus material on the surface of a neoplasm with the resultant appearance of a solid calculus. Other tumors with a necrotic surface can look the same as a soft, infection stone covered with inflammatory debris. In these and many other situations, other interventional endoscopic maneuvers are necessary to obtain an accurate diagnosis.

Aids to visual diagnosis of neoplasms, such as HexFix or narrow-band imaging (NBI), have been used in the bladder to detect carcinoma *in situ* or additional exophytic tumors. These techniques have been used in the upper tract only in short series without definitive findings [25].

Endoscopic biopsy

Ureteroscopic biopsy is an important procedure to sample neoplasms in the upper urinary tract and give a tissue diagnosis. It is of value in determining the malignancy of a lesion and the grade of a TCC. Ureteroscopic biopsy is limited because of the size of the working channel within the ureteroscope and the subsequent limitation in the size of the biopsy instrument that can be used. For example, a piece of tissue obtained with 3F cup biopsy forceps will be less than 1 mm in diameter, which is usually too small to be prepared for histologic study using standard techniques; it is often lost in the process (see Video 41.1A). In contrast, it is a relatively large fragment of tissue for cytologic techniques. It can be prepared as a cell block, and stained and examined as a histologic preparation to give a diagnosis and information on grading.

Several different biopsy instruments and techniques are available. Abdel-Razzak *et al*. evaluated samples from 55 procedures in 44 patients with a possible diagnosis of upper tract TCC [26]. They compared the diagnostic yield, considering only those samples that were specifically positive or negative for malignancy. Those that were "suggestive" or equivocal were not considered diagnostic. The techniques compared aspiration of urine at the level of the lesion, wash and aspiration with saline solution of the area of the lesion, and direct tissue sampling with brush, basket, or biopsy forceps. The tissue sampling techniques gave the best yield, particularly the flat wire basket for large friable tumors and the cup forceps for more sessile lesions. The brush was less effective and under endoscopic vision was observed to move the more flexible tissue without removing fragments. It may be more useful with flat or sessile lesions. Aspiration and wash proved to be valuable in providing a diagnosis for some patients in whom the other sampling techniques were inconclusive.

A flat wire basket is quite effective for removing large fragments of papillary tissue with a small diameter ureteroscope (see Video 41.2A–C, 41.6). Under endoscopic vision, the basket is placed on the tumor and partially closed. The entire unit, consisting of tumor sample, basket, and ureteroscope, is then removed from the ureter and bladder. In this way a large sample can be

Table 41.1 Specimens for cytology.

Bladder urine
Aspirate at tumor
Biopsy
Aspirate after biopsy
Aspirate after treatment

Table 41.2 Effect of ureteroscopic biopsy [40].

	Biopsy	None
Number of patients	48	48
Metastases (5%)	12.6	18.8 (NS)
Died with recurrence (%)	10.4	10.4 (NS)

removed (up to 1 cm in diameter), which is adequate for cytologic or histologic study. The ureteroscope is then reinserted to repeat the inspection and biopsy or to treat the neoplastic lesion.

One of the most important steps in handling the tissue for pathologic diagnosis is to work closely with the cytopathologist [27–30]. Samples are examined with both a smear and cytospin preparation. If there is any macroscopically visible tissue in the sample, a cell block is also prepared. This sample, if adequate for cell block, often demonstrates both the architecture of the neoplasm and the individual cells to allow grading of TCC. Multiple samples of the lesion are taken. In addition, urine and saline wash samples at the lesion before and after biopsy and/or treatment are also obtained (Table 41.1).

Grading

Grading of upper tract TCC is important in determining the prognosis and directing therapy. The grade obtained from ureteroscopic biopsy has been shown to reflect the grade of the overall tumor with reasonable accuracy. In 42 patients, Keeley *et al*. found that the grade seen on a ureteroscopic biopsy prior to surgical treatment matched that in the final pathologic specimen in 86% of cases [31]. Danashmand *et al*. showed an overall accuracy of 90% in patients who had surgery early after biopsy or within 2 months after ureteroscopic diagnosis [32]. Combined cytology and ureteroscopic biopsy have been particularly valuable in accurately diagnosing patients with grade II TCC [33].

Staging

Accurate staging of upper tract TCC has not been possible with endoscopic techniques alone. The search for metastases includes the usual abdominal CT scans or MRIs and chest radiographs. Determining the depth of invasion of the primary tumor or other simultaneous lesions remains difficult, and most series have not reported accuracy in determining it. One series advocated multiple deep biopsies with cup forceps in an attempt to determine the presence of tumor in the lamina propria [34].

The grade of the primary tumor has often been associated with stage, but it cannot be considered to be truly accurate staging. In Keeley *et al.*'s series, increasing stage correlated with increasing grade seen on ureteroscopic biopsy [31]. Brown *et al*. also found that the grade on endoscopic biopsy correlated with the final pathologic stage in nephroureterectomy specimens [35]. Other series of patients treated surgically have also demonstrated the relationship of increasing stage with increasing grade [36].

Endoluminal ultrasound has been used in one series in an attempt to determine the depth of invasion [37]. It has shown some value but is severely limited by the availability of the instruments.

Complications

There remains some concern that the ureteroscopic biopsy of an upper urinary tract neoplasm can disseminate tumor cells locally or systemically. The possibility of pyelovenous or pyelolymphatic backflow has been cited as a possible mechanism. In a single case report, tumor cells were found outside the kidney in a nephroureterectomy specimen after ureteroscopic biopsy [38]. However, in a review of 13 nephroureterectomy specimens following ureteroscopic biopsy, no unusual metastatic pattern was seen [39]. In a well-controlled study of 96 patients, Henden *et al*. found no difference in long-term or disease-specific survival in patients with upper tract TCC who had surgical treatment preceded either by ureteroscopic biopsy or not (Table 41.2) [40]. Hara *et al.* reported on 50 patients who had ureteroscopic biopsy without development of metastatic disease [41]. From these series it can be concluded that ureteroscopic biopsy can be a safe and very valuable procedure without any documented evidence of tumor dissemination.

Selection of patients for ureteroscopic biopsy

Ureteroscopic biopsy is of value in any patient with an upper tract filling defect in whom the diagnosis is questioned. Voided urinary cytology is a less than definitive (positive) diagnostic test for malignant cells in patients with a filling defect. The presence of individual malignant appearing cells (positive cytology) indicates either carcinoma *in situ* or a high-grade neoplasm. Biopsy may be avoided in patients with cytology that is definitively positive for malignant cells and who have a large irregular upper tract filling defect, findings that can be considered classic for TCC. However, even these patients should have endoscopy to rule out associated bladder tumor.

Ureteroscopic treatment

The advent of ureteroscopic access to the entire upper urinary tract has also provided options for the treatment of upper tract neoplasms. These procedures are based on the extension of diagnostic procedures. Many devices can be placed through the working channel of the ureteroscopes to treat neoplasms [42]. These include graspers, electrodes, and laser fibers. There has been considerable interest and wide acceptance of these techniques for the treatment of some upper tract neoplasms. The techniques for treatment and selection of patients are evolving as the value of this approach is being defined in relatively small series of patients.

The rationale for conservative endoscopic therapy of upper tract neoplasms was based initially on the success of other conservative treatment modalities for similar lesions. These series have defined the role of conservative treatment in the high-risk patient and have extended such therapy to other specific lesions. Conservative surgical techniques have been used to treat upper tract tumors with mixed results, depending on the nature of the tumor and its location. Endoscopic treatment is a natural extension of these nephron-sparing procedures, evolving only as the instruments have become available. Similarly, these techniques can be considered an extension of endoscopic procedures used at the bladder level for the treatment of TCC of the bladder. Since these series have not shown a prohibitive risk, other series in progress will continue to define appropriate applications of endoscopic therapy. There has been considerable growth in the application of endoscopic treatment of upper tract tumors with survey evidence of it being performed by academic and nonacademic urologists [43].

Natural history and prognosis after surgical therapy

The natural history of neoplasms in the upper urinary tract must be considered in order to define the optimal mode of therapy. TCC constitutes the vast majority of endoluminal tumors in the upper collecting system; there remain a few benign lesions which can be considered separately. Since ureteroscopic access will allow treatment of endoluminal lesions only, TCC is, for practical purposes, the only malignant neoplasm to be considered for treatment.

The behavior and prognosis of upper tract TCC , in both the ureter and the intrarenal collecting system, has repeatedly been shown to relate to the grade and stage of the lesion. In a series by Charbit *et al*., the overall survival rates at 5 and 10 years after treatment were 67.3% and 64.9%, respectively [36]. Only 19.5% of patients died of metastases from the upper tract tumor, 86% died within 1 year postoperatively, and the remainder died within 2 years. Among those with tumor-related deaths, 90% had high-grade tumors (grade II or III/IV) and 86% had presented with muscle invasion. Nielsen and Ostri reviewed 36 patients treated surgically for primary carcinoma of the renal pelvis and found that six of 22 patients (27%) with grade II/IV TCC and eight of 11 (80%) with grade III/IV lesions died from their disease [44]. Both of the patients with grade IV TCC also died of this disease. The prognosis was statistically significantly poorer for patients with grades III and IV Ta than those with grade II. Survival of 49 patients with grade I Ta of the ureter or renal pelvis collected at the Mayo Clinic over a 22-year period was identical to that of an age-matched control group [45]. In contrast, survival with higher grade Ta correlated with tumor stage and grade, and was consistently lower than in a control group [46].

The close relationship between grade and stage is also reflected in the prognosis. Mufti *et al*. found that survival of patients with superficial well-differentiated tumors was greater than 90% in groups treated either by total nephroureterectomy or by more conservative resection [47]. In the series of Nielsen and Ostri, only three patients (14%) with grade II/IV lesions had invasion of connective tissue while 10 (91%) with grade III lesions and both patients with grade IV had invasion [44]. In the series by Charbit *et al*., 79% of the grade II/III tumors had invaded into or beyond the muscle layer [36]. Lymphadenectomy was negative in all patients with low-grade tumors in whom it was performed, while 39% of those in patients with higher grade tumors were positive.

The grade of the primary lesion also indicates the extent of mucosal abnormality. McCarron *et al*. systematically mapped nephroureterectomy specimens and found that the grade of the principle neoplasm paralleled the extent of epithelial disturbance in the otherwise normal appearing urothelium [48]. They found that high-grade carcinomas were associated with severe epithelial changes and low-grade cancers with hyperplasia only. Cytologic study of specimens collected either from the upper tract (17 of 30 cases) or bladder urine (13 cases) accurately reflected the grade of the principle neoplasm. It also indicated the presence of both contiguous and remote abnormalities. Among seven patients with grade I/III tumors, six had negative cytologic studies and one was suspicious for carcinoma. However, among those with grade III lesions, 10 were positive for malignant cells, three were suspicious, and only one was negative.

Mazeman reported that a multiplicity of tumors formed a negative prognostic factor; only 20% of patients with multiple tumors survived for 5 years while 37% with single tumors survived for 5 years [49]. Survival was the same whether the primary tumor was within the renal pelvis, intrarenal collecting system, or ureter.

Standard surgical treatment of TCC of the upper urinary tract has been nephroureterectomy including a cuff of bladder. High recurrence rates have been noted when a less extensive operation has been performed, particularly with more proximally located lesions. Mazeman noted that there was a recurrence rate of 19% after total nephroureterectomy [49]. This increased to 24% after subtotal nephroureterectomy, 32% after partial nephroureterectomy, and 48% after nephrectomy alone. Recurrences were noted to be distal to the primary tumor in any part of the urinary tract, the majority in the bladder around the orifice. There is a low rate of occurrence in the contralateral kidney. The risk of bladder cancer in patients presenting initially with an upper tract urothelial tumor was approximately 9% and that of a contralateral urothelial tumor was 1%. In those with a previous history of bladder tumors, the risk of another vesical lesion was 53% [36]. Among patients with grade II or III/IV lesions in a Mayo Clinic series, the incidence of bladder tumor was 30% [46]. Based on these and similar findings, recommendations for follow-up have included cystoscopy at intervals of 3–4 months and imaging of the remaining upper tracts at 1 year. Recommendations for continued evaluation of the upper tract vary after that period.

There has been a very strong trend toward laparoscopic nephroureterectomy rather than open surgical treatment.

Conservative surgical therapy

Conservative, nephron-sparing surgery for upper tract TCC has been attempted in special circumstances in patients with a solitary kidney who are not candidates or who refuse to become anephric, and those with a compromised contralateral kidney, including bilateral tumors. There is also evidence that low-grade and -stage distal ureteral tumors can be treated by distal ureterectomy alone.

Major series have reviewed the results of local surgical treatment of upper tract tumors both in the renal pelvis and the ureter. Generally, there has been a higher recurrence rate after the treatment of renal pelvic tumors and a much lower rate for ureteral tumors. Mazeman [49] and Zincke and Neves [50] reported recurrence rates of 45–65% after the local resection of renal pelvic TCC, and 15–16% after resection of ureteral lesions. The lesions treated, however, included a wide range of grade and stage. These and other series have found that distal ureterectomy for low-grade TCC in the distal ureter is often curative [45, 51–53]. Based on these results, some have recommended distal ureterectomy as primary therapy for distal ureteral lesions.

In summary, recommendations for conservative surgical therapy of upper tract TCC include high-risk patients, and those with a solitary kidney, a compromised contralateral kidney, including bilateral tumors, or overall compromised renal function. Also included are those in whom nephroureterectomy would be an overwhelming medical risk. Low-grade and -stage, distal ureteral tumors can be successfully treated with distal ureterectomy [45, 51–54].

Diagnosis, staging, and grading

Diagnosis of an upper tract lesion suspicious for neoplasm is essential before considering any form of therapy. In brief, it is now usually possible to diagnosis upper tract filling defects which have been detected by radiographic studies but await endoscopic evaluation and sampling for a final diagnosis.

Grading of TCC has also been possible with endoscopic sampling combined with cytopathologic techniques [55–57]. Others have previously demonstrated that high-grade lesions more frequently shed cells giving positive urinary cytologic findings [45, 48, 57]. Since low-grade tumors may shed papillary structures, indicating the presence of low-grade malignancy, a distinction in grading can sometimes be made on the basis of cytologic findings from the urine alone. This has been extended to endoscopic sampling techniques.

Staging of TCC in the upper tract has been important to direct treatment and indicate prognosis. A search for metastatic disease and renal parenchymal invasion by TCC is the same whether the treatment to be considered is surgical or endoscopic. Only when there is a decision to be made regarding radical or conservative (including endoscopic) therapy does it become important to determine the stage preoperatively by learning whether there is local invasion by the neoplasm. The techniques available have generally failed in any attempt to establish the stage of low-stage lesions.

Endoscopic therapy

Endoscopic therapy of TCC is familiar and well accepted for lesions in the urinary bladder. The concept is new only when applied to lesions in the upper urinary tract. The instruments and techniques for endoscopic access for both diagnosis and treatment, as well as follow–up, are now available. The size of endoscopes employed, the ablative devices available, and the access with rigid or flexible ureteroscopes must be considered in any endoscopic approach to upper tract tumors. The neoplasm

Table 41.3 Tumor factors used in the selection of patients for ureteroscopic treatment.

	For	Against
Size	Small	Large
Configuration	Papillary	Sessile
Number	Solitary	Multiple
Distribution	Single	Circumferential or extensive
Grade	Low	High
Cytology	Negative	Positive

itself, including its diagnosis, grade, location, and size, must also be considered in any decision for endoscopic treatment in an individual patient (Table 41.3). Ureteroscopy has become the major endoscopic technique for the diagnosis and treatment of upper tract neoplasms. However, it is used with the complementary techniques of percutaneous nephroscopy for resection of larger neoplasms and laparoscopic nephroureterectomy or distal ureterectomy.

Several techniques are available that can be applied to the treatment of upper tract neoplasms ureteroscopically. These techniques, which can remove or ablate tissue within the upper tract using rigid or flexible ureteroscopes, include mechanical removal, electrosurgical resection, fulguration, and laser therapy. These are considered in greater detail because of their importance in treating neoplasms within the upper urinary tract.

The techniques used for the ureteroscopic biopsy of tumors result in the removal of tissue volume. A flat wire basket can remove several millimeters of papillary tumor with each application (see Video 41.6). Although the cup biopsy forceps remove a small volume with each bite, repetitive sampling can remove a small tumor (see Video 41.1A). The base of the tumor can then be coagulated with one of the other instruments (see Video 41.1B).

Electrosurgical techniques similar to those used in the bladder have been applied for small distal ureteral neoplasms. Historically, resection was the first to be used for treatment of upper tract neoplasms [58, 59]. Rigid ureteral resectoscopes, similar to a long version of a pediatric resectoscope, can be used in a similar fashion to other resection procedures for tumors in the distal ureter. The resectoscopes are relatively large, approaching 12–13F. The loop takes a small bite of tissue and it may become necessary to clean the loop before removing the next piece of tissue. This is often a slow procedure. After resection, the base of the tumor can be lightly fulgurated. Extreme care should be taken to avoid resecting through the full thickness of the ureteral or renal pelvic wall, and also to avoid fulgurating a large area of the ureter, which can result in scarring and stricture formation [60]. Electroresection has been superseded by other more efficient techniques.

The other major electrosurgical technique is simple fulguration with an electrocautery probe. This technique is suitable for very small lesions or for the base of a tumor after removal of the bulk of the volume of the lesion. Small probes of 2–3F are available and can be passed through the channels of small-diameter rigid or flexible ureteroscopes. Again, care should be maintained to avoid fulgurating large areas of the ureter. This electrocautery technique is also useful for lesions within the intrarenal collecting system, particularly in the lower pole medially where the laser fiber cannot be deflected by the ureteroscope to approach the tumor. The 2F electrode is slightly more flexible and can fulgurate with lateral contact rather than the directly forward approach needed with laser therapy (see Video 41.5B).

Laser techniques have been widely applied for the treatment of upper tract neoplasms and have proven to be the most efficient technique. Small fibers of either 200- or approximately 400-μm core diameter can be passed through the flexible ureteroscope. The two major lasers currently available for urologic application can effectively treat upper tract tumors with coagulation, ablation, and resection. The neodymium (Nd):YAG laser is the first laser to be used both for treatment of bladder tumors and for ablation of renal pelvic and ureteral neoplasms. It was first used with open surgical techniques to ablate TCC in the renal pelvis and intrarenal collecting system [61]. Long-term cure without recurrence has been achieved with this technique. The Nd:YAG laser was subsequently used ureteroscopically to ablate TCC of the ureter [62]. In a comparative series, Schmeller and Hoffstetter demonstrated the success of laser ablation of upper tract tumors with the development of fewer ureteral strictures than after electrocoagulation [63].

The Nd:YAG laser can penetrate several millimeters into tissue after several seconds of exposure. This can be controlled by positioning the fiber onto the tumor without directly aiming it toward the wall of the ureter, and by moving the fiber across the surface of the tissue to avoid prolonged exposure. Ureteral damage is limited since the laser fiber and beam are aimed at the tumor parallel to the surface of the kidney. Within the kidney, especially the renal pelvis, where there is a greater surface area and less risk of scarring and stricturing, the neoplasm can be coagulated safely with the Nd:YAG laser [64] (see Video 41.3). The laser is activated at 20–30 W on continuous mode and moved over the surface to coagulate the tissue. The effect can be seen as the color of the tissue changes to white. The laser fiber should not touch the tissue when it is activated because the tip will then char. For a relatively large lesion obstructing the ureter or an infundibulum, it may be necessary to remove some of the coagulated tissue to determine whether viable tumor remains after a single application. Since the laser can penetrate to a depth of approximately 5–6 mm, it may not affect the entire depth of the tumor. Coagulated tissue is removed with a grasper or basket to expose portions of the tumor otherwise not visible ureteroscopically. The remainder of the tumor is then treated similarly. There have been no reports of major renal or vascular injury or damage to associated organs from forward scatter of the Nd:YAG laser used in the renal pelvis.

The holmium (Ho):YAG laser has been widely applied for urologic indications. It is a solid-state pulsed laser that can fragment calculi, and coagulate, ablate, and remove tissue. This laser produces light at a wavelength of 2100 nm, which can be carried along low water content fiber. The laser energy is absorbed within less than 0.5 mm of tissue or fluid and has essentially no risk of forward scatter. The effect observed is the only tissue effect achieved (Figure 41.1). This laser is particularly useful for ureteral lesions since it can ablate and remove a visually occlusive neoplasm to open the lumen for inspection more proximally [65–67] (see Video 41.4).

The laser fiber must be placed in contact with or very close to the tissue to be treated. The laser is then activated at energies from 0.5 to 1 J at a frequency of 6–10 or even 15 Hz. Irrigation is maintained to clear the visual field of tissue debris. It is often necessary to discontinue treatment to allow the field to clear, since considerable debris is formed during treatment. Bleeding occurs occasionally and can be controlled better at lower energies or by moving the fiber slightly away from the tissue to diffuse the laser beam and improve coagulation. There is also clinical evidence that a longer pulse duration, such as 700 ms, rather than the 350 ms often used for lithotripsy, will also improve coagulation (see Video 41.5A). The very limited penetration allows precise control and the laser, thus, can be used for lesions located at the level of the iliac vessels and the renal pelvis near the renal vessels. Great care is employed to avoid ablation and resection through the wall of the ureter or renal pelvis itself.

The argon laser has major theoretical advantages for endoscopic treatment as well. Wavelengths of 488–514 nm have been used to treat superficial bladder cancer and also ureteral neoplasms. The penetration is limited to 1 mm and the laser light can be delivered with a fiber of 300 or 600 µm diameter. Johnson reported treating tumors with continuous wave argon laser energy with a quartz fiber, utilizing a contact mode with the power set at 5 W [68]. There was satisfactory ablation of tumors in all three patients, but other confirmatory reports are still not available.

The thulium laser has a wavelength of 1.946–2.013 µm with the advantage of coagulation similar to the Nd:YAG laser and cutting capabilities. It does not have the ablative effect of the holmium laser. Only preliminary reports, which have been favorable, are available.

These lasers can also be used in combination. The effects of the Nd:YAG and Ho:YAG lasers are complementary. The Nd:YAG laser can be used to coagulate the major volume of tumor since it penetrates several millimeters and can achieve coagulation effect within the depth of the tissue. The coagulated tissue can then be removed mechanically or even more effectively with the Ho:YAG laser. The Ho:YAG laser can then be used to resect the tissue to the level of the wall of the ureter or renal pelvis. Thus, the benefits of each device can be used to the best advantage.

Results of treatment

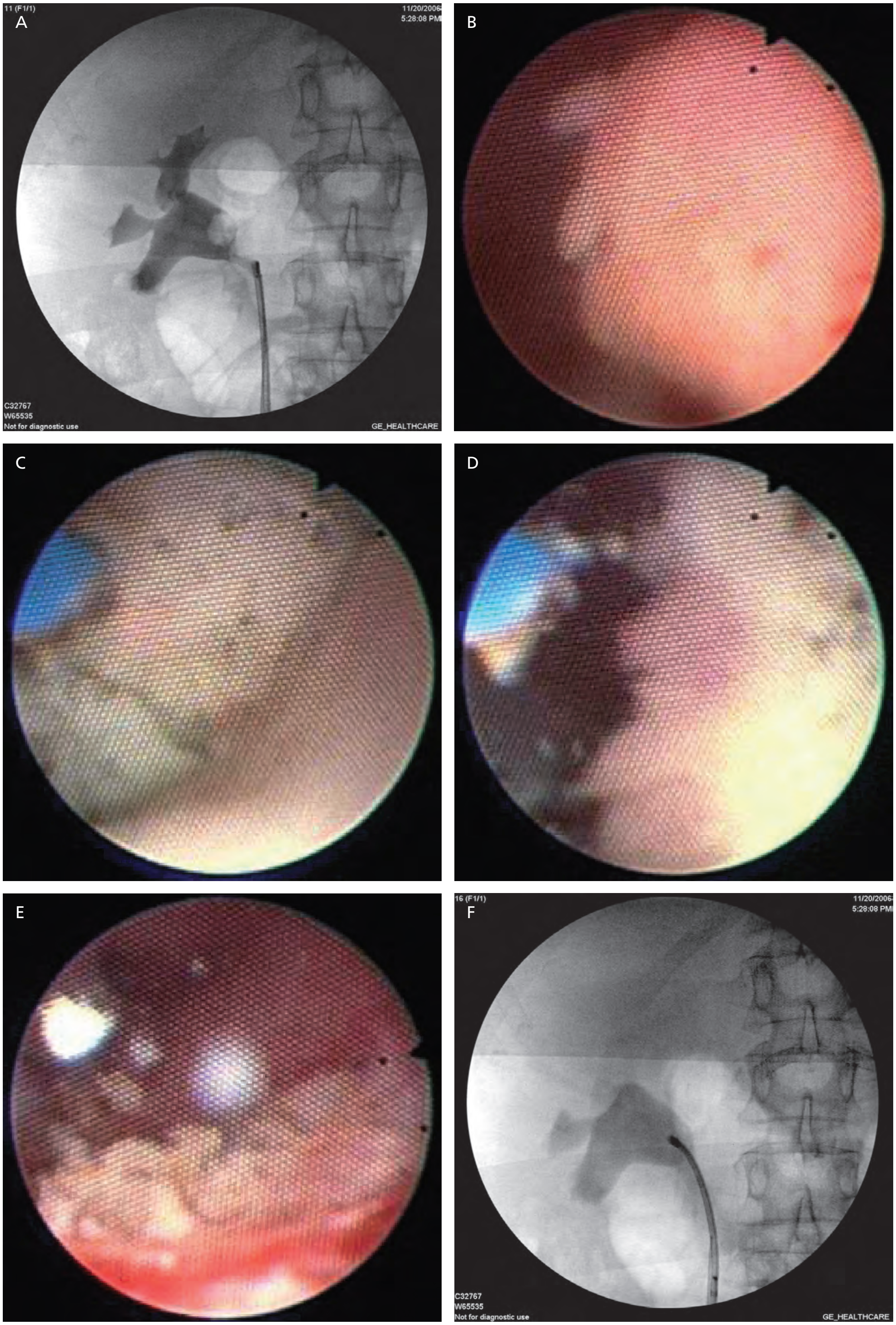
The results of ureteroscopic treatment of upper tract TCC have been reported in several relatively small series. The techniques used for treatment, the location and characteristics of the tumors, and follow-up techniques and duration have varied widely. In the early report of Huffman *et al*. on the treatment of upper tract urothelial tumors, eight patients with low-grade tumors were treated by ureteroscopic fulguration or resection [58]. Surveillance was continued every 3 months with an average follow-up of 21 months. There were asynchronous recurrences in three patients which remained low grade and no patient required surgical treatment during the study period. Grossman *et al*. reported a higher recurrence rate in patients all treated endoscopically [69]. Among their eight patients, two were eventually treated surgically. One required a nephroureterectomy after the ureter could not be negotiated with the ureteroscope for treatment of a recurrence.

Several larger series since these earlier reports have expanded the acceptable limits of treatment, including larger proximal lesions, and some have included higher grade tumors. Overall, this has resulted in a relatively high recurrence rate with a wide variation and an increasing need for nephroureterectomy, but stable development of new bladder tumors [70–81].

Recurrences

TCC of the upper urinary tract recurs at significant rates, just as locally treated bladder tumors do. There too it is impossible to determine whether the recurrence is the result of implantation of cells from the original tumor or if it is related to a field change in the urothelium. Successful treatment depends upon thorough treatment of the primary neoplasm without irreversible damage to the organ system, coupled with the lack of local recurrence of the neoplasm as well as a lack of metastases. Several factors come into play in the adequacy of treatment.

Conservative surgical treatment with open excision of solitary upper tract lesions also results in significant


11 (F1/1)
11/20/2006
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A
C32767
W65535
Not for diagnostic use
GE_HEALTHCARE
B
C
D
E
16 (F1/1)
11/20/2006
5:28:08 PM
F
C32767
W65535
Not for diagnostic use
GE_HEALTHCARE

Figure 41.1 (A) Fluoroscopic view of the right collecting system with contrast demonstrates the filling defect based on the medial wall. (B) Endoscopic image of the grade I–II transitional cell carcinoma before treatment. (C) Tumor is coagulated with a Nd:YAG laser. (D) Coagulated tissue is resected with the Ho:YAG laser. (E) Tumor has been resected to the base along the contour of the renal pelvis. (F) Fluoroscopic view of the renal pelvis after ureteroscopic resection demonstrates the absence of a mass or evidence of extravasation.

local recurrence. As noted above, the recurrence for ureteral lesions is approximately 12–18% and higher when more proximal lesions were removed. Renal pelvic lesions treated surgically recur at an even higher rate of 48–66% [49, 50, 79].

In collected series reporting ureteroscopic treatment of upper tract tumors during the early experience through 1995, there was a higher recurrence rate for renal pelvic lesions (40%) than ureteral lesions (25%). However, during the following 5 years, there was an increase in the recurrence of ureteral tumors (43%) with renal pelvic tumors stable at 37%. During that time, the rate for nephroureterectomy increased from 4% to 14%. Thus, it can be speculated that the difference is related to the ureteroscopic treatment of larger and more proximal ureteral lesions in the later years. Higher recurrence rates can be expected from these lesions.

More recent studies are more difficult to compare since they have included a wide range of tumor sizes and even higher grade lesions. Recurrences have been seen in up to 80% or more of patients in some series. We have found that most of the recurrent lesions are small and can be treated endoscopically. Only when there are extensive and rapid recurrences does nephroureterectomy become necessary (Table 41.4) [83–85].

These series are also characterized by high disease-specific survival, with the two notable exceptions of the series reported from the Mayo Clinic of patients presenting initially with bladder tumors, and in those in whom imperative indications such as a solitary kidney prompted their endoscopic treatment. It is notable that in many of the patients, biopsy confirmation was not available and high-grade recurrences developed [86, 88, 89].

Several characteristics of primary upper tract TCC appear to be related to the risk of recurrence (Table 41.5). Some of these characteristics are similar for to those for risk of recurrence for bladder tumors. Recurrent disease is more likely for tumors over 1.5 cm in diameter than for smaller lesions. There is also a higher risk of recurrence for high-grade tumors treated either ureteroscopically or by open surgery. There is evidence that positive urinary cytology at the time of treatment is a poor prognostic sign. The effect of the location of the primary tumor, whether in the intrarenal collecting system or ureter, has been inconsistent, with some series reporting a higher rate for intrarenal neoplasms and others finding no difference or more frequent recurrence after ureteral primaries. However, multifocal lesions have consistently been seen to be associated with more frequent recurrences, both in the upper tract and in the bladder.

Bladder tumors

There is significant risk of new bladder tumors developing in patients with upper tract neoplasms. In a summary of several series reporting laparoscopic and open nephroureterectomy, the subsequent bladder tumor rate was 31.1% after laparoscopic treatment and 30.1% after open surgery. However, there was a wide range in each group: 10–55% in the laparoscopic group and 15–45% in the open surgical group [90]. Additionally, one series compared bladder recurrences after retroperitoneoscopic or open nephroureterectomy without finding any difference [91]. Among patients with upper tract tumors treated ureteroscopically, the average subsequent bladder tumor occurrence rate was 38.7%. In two series of patients without previous bladder tumors, the rate was 34% and 33%, respectively (Table 41.6).

Some series have noted that the bladder tumor rate is related to the grade of the primary tumor, while the effect of grade was not considered in others. One report

Table 41.4 Recurrence after ureteroscopic treatment of upper urinary tract transitional cell carcinoma.

Series	Number	Recurrences (%)	Disease-specific survival (%)
Martinez-Piniero *et al.* 1996 [83]	28	29	93
Tawfiek and Bagley 1997 [84]	205	31.7	NS
Keeley *et al.* 1997 [85]	41	28	100
Elliot *et al.* 1996 [76]	44	38	86.5
Chen and Bagley 2000 [7]	23	65	100
Daneshmand *et al.* 2003 [32]	26	88	100
Suh *et al.* 2003 [77]	18	37.5	100
Johnson *et al.* 2005 [80]	35	68	100
Sowter *et al.* 2007 [86]	35	74	100
Thompson *et al.* 2008 [87]	86	55	100
Cornu *et al.* 2010 [82]	35	60	100

Table 41.5 Factors related to increased risk of tumor recurrence.

Multifocality
Tumor grade
Tumor size
Abnormal cytology
Previous bladder tumor
?Tumor location

Table 41.6 New or recurrent bladder tumors after ureteroscopic treatment of upper urinary tract transitional cell carcinoma.

Series	Bladder tumor	%
Sowter *et al*. 2007 [86]*	12/35	34.3
Thompson *et al*. 2008 [87]	37/83	44.6
Daneshmand *et al*. 2003 [32]	6/30	20.0
Chen and Bagley 2000 [7]**	41/101	40.5
Cornu *et al*. 2010 [82]	14/35 (8/24)*	40.0 (33.3)*
Combined	110/284	38.7

*No history of bladder tumor.
**Reviewed series to 2001.

found that the rate of new bladder tumor was related to a previous history of bladder cancer, where a 53% bladder tumor rate was noted [36]. There appears to be no major difference between the rate of bladder tumors seen after ureteroscopic treatment or open or laparoscopic nephroureterectomy, although it is a few percentage points higher in the ureteroscopy group. One review of 89 patients with total nephroureterectomy for localized TCC of the upper tract showed a direct effect of tumor multiplicity and surgical modality, with bladder tumor rate with laparoscopic treatment higher than with open surgery. An inverse relationship between tumor size and pathologic stage on subsequent development of bladder cancer was also noted [92].

Large tumors

Large neoplasms of the upper tract can be treated successfully ureteroscopically in some patients. It may be necessary to stage treatment at intervals of approximately 8 weeks and to use a combination of Nd:YAG laser coagulation or electrocoagulation with holmium laser resection. If visibility deteriorates with bleeding or tumor debris, it may be impossible to distinguish the margin of the tumor. The second resection may allow more precise treatment. Some tumors that regrow too rapidly or are too large to be treated ureteroscopically may require a percutaneous nephroscopic procedure or even nephroureterectomy.

High-grade tumors

In general, high-grade tumors have not been considered good candidates for ureteroscopic treatment because of the risk of invasion, metastatic disease, and rapid recurrence. However, in some specific patients, ureteroscopy may be the preferable option for the management of a high-grade upper tract neoplasm. The same ureteroscopic techniques would be employed. There is some evidence that high-grade lesions will recur more frequently, but long-term successes have also been reported [77]. The patient must be informed of the risks of resection and be able to participate in subsequent endoscopic surveillance. A survey of endourologists showed that 77% favored a distal ureterectomy for a large distal ureteral tumor. Only 21% thought that ureteroscopic ablation for such a lesion would be the first choice [43].

Normal contralateral kidneys

Initially, the ureteroscopic treatment of upper tract TCC was limited to patients with a solitary kidney or abnormal contralateral kidney. Based on the success of this experience, ureteroscopic treatment has been extended to patients with a normal contralateral kidney. The feasibility of this approach was demonstrated in studies looking specifically at patients who had two kidneys. More recently, patients with two normal kidneys are generally included in reported series.

Elliott *et al*. reviewed 21 patients with two kidneys and found that 37% developed local recurrence at an average of 7 months after treatment [75]. There was a 46% recurrence rate among 13 ureteral tumors and only 12% (one of eight) for renal pelvic tumors. There was, however, a high mortality rate with 11 of 20 patients dying of unrelated causes, with one dying from invasive bladder cancer. There were no deaths related to the endoscopic tumor treatment or the upper tract neoplasm. Only four patients (19%) required nephroureterectomy. The high unrelated mortality rates suggest that these patients are generally at high risk.

In a series by Chen and Bagley, 23 patients with two functional kidneys were treated ureteroscopically [93]. The patients had several recurrences, but there was no significant grade increase and no patient developed metastatic disease. At the time of their follow-up, 17% had an ipsilateral recurrence and 5% (one patient) had developed a new contralateral neoplasm. However, 61% of patients were free of disease. Four (17%) had required nephroureterectomy.

Matsuoka *et al.* reviewed their experience with ureteroscopic treatment of upper tract tumors and found that there was a higher recurrence rate (86%) among patients treated for a strong indication, such as a solitary kidney, while it was only 20% in those treated electively [78]. Thus, the results again appear to be related to patient selection.

Thompson *et al.*'s series reported 83 patients with normal contralateral kidneys and demonstrated a recurrence rate of 55% [87]. The last follow-up noted that 33% of patients required nephroureterectomy and 11% had died from TCC. However, it was noted that over half the patients had a diagnosis based on visual inspection alone and 21% of those had developed grade III TCC during follow-up.

In summary, ureteroscopic treatment of upper urinary tract TCC can be performed safely and effectively with preservation of renal units even in patients with a normal contralateral kidney. The same factor of long-term function used to promote partial nephrectomy for renal cell carcinoma should be considered also to apply to patients who have TCC. Every effort should be made to preserve renal mass when possible.

Surveillance

Surveillance after ureteroscopic treatment of upper tract neoplasms is essential because of the high recurrence rate. Almost every paper reviewing experience with this treatment has cautioned that endoscopic surveillance is necessary. Cystoscopy has been well-established as the standard technique to evaluate for new bladder neoplasms after surgical treatment of upper tract neoplasms. After endoscopic treatment, surveillance of the bladder must also be maintained with cystoscopy. Evaluation of the upper tracts for new or recurrent tumors must be maintained with other techniques. Ureteroscopy is the most sensitive technique to evaluate the upper tract and should be used routinely in follow-up surveillance. Grossman *et al*. reported one patient with diffuse upper tract TCC detected by ureteroscopy and confirmed on nephroureterectomy who had a normal excretory urogram [69]. Keeley *et al*. found that the sensitivity of retrograde ureteropyelography for detecting recurrent upper tract tumors was only 25% [85]. In another series, urinalysis, voided cytology, retrograde ureteropyelography, and ureteroscopic biopsy were compared in patients with ureteroscopically visualized and treated tumors [94]. None of those tests could accurately and routinely detect tumors. There was a high specificity of bladder urine cytology and urinalysis, which do support their use. If they are abnormal, earlier endoscopy should be undertaken. At this time, the role of FISH in detecting recurrent upper tract tumors appears to be minimal.

Various surveillance protocols have been proposed. Some authors recommend excretory urography or retrograde ureteropyelography at intervals of 3–6 months, with ureteroscopy used only when specifically indicated. However, the greater sensitivity of direct endoscopic inspection must be recommended as a major technique for surveillance. Ureteroscopy is continued at intervals of 3 months until the upper tract is clear, at which time the patient is examined ureteroscopically at 6-month intervals. Cystoscopy and cytology with urinalysis are continued at intervals of 3 months during the first 2 years (Table 41.7). Evaluation of the contralateral collecting system with retrograde pyelography should be performed at least yearly and possibly at 6-month intervals.

Table 41.7 Surveillance.

3-month intervals:
  Cystoscopy
  Cytology

6-month intervals (after tumor free):
  Ureteroscopy

6 or 12 month
  Imaging of contralateral kidney
  (Intravenous pyelogram or retrograde)

Complications

Complications can occur with any ureteroscopic procedure but there are some that appear to be specific to ureteroscopic tumor treatment. Many of the problems related to dilation of the UPJ can be avoided by the use of small diameter rigid and flexible ureteroscopes. Electroresection is rarely used, and therefore the complications inherent in that procedure are uncommon. With any of the techniques commonly used, electrocoagulation, laser coagulation or resection with a Nd:YAG or Ho:YAG laser, there remains a risk of stricture from scarring of the ureter or an infundibulum. A review of complications from published series of ureteroscopic treatment of upper tract tumors indicates a ureteral stricture rate of 13%, which is considerably higher than the rate of less than 1% seen for stone treatment [95]. This may be an inherent risk of ureteroscopic tumor treatment, since the ureter itself is specifically traumatized with the treatment of the neoplasm. In comparison, damage to the ureteral wall during stone treatment is diligently avoided (Table 41.8).

Perforation remains a strong theoretical risk. However, reported series have not shown any strong propensity toward intraluminal tumor dissemination, implantation, extraluminal tumor, or tumor extension. As noted above, there is no increased risk of tumor recurrence with ureteroscopic biopsy [40].

Adjuvant therapy

Adjuvant chemotherapy or immunotherapy is an attractive option in the treatment of upper tract TCC, particularly in view of the high recurrence rate. The safety and potential advantages of adjuvant therapy have been demonstrated in several short series but this treatment has no proven role.

Bacillus Calmette-Guérin (BCG) has been used as topical therapy in the upper tract with positive cytology. Sharpe *et al*. administered BCG through retrograde

Table 41.8 Strictures after ureteroscopic treatment of upper urinary tract transitional cell carcinoma.

Series	Patients	Stricture	%
Suh *et al.* 2003 [77]	16	2	12.5
Daneshmand *et al.* 2003 [32]	30	5	16.7
Johnson *et al.* 2005 [80]	35	3	8.5
Sowter *et al.* 2007 [86]	40	4	10.0
Chen and Bagley 2001 [95]	*139	19	13.7
Combined	260	33	12.7

*Combined series to 2001.

ureteral catheters in patients with abnormal lateralizing cytology [96]. Seventeen renal units were treated in 11 patients and the urinary cytologic specimen normalized in eight of the 11 patients with a median follow-up of 36 months. One patient experienced fever and required antituberculosis therapy, but there were no other complications in the group. Schoenberg *et al*. also reported percutaneous instillation of BCG. One of nine patients developed fever [97]. Belman *et al.* reported that four of 32 patients treated with BCG after percutaneous tumor resection developed asymptomatic renal granulomatosis and three had fever that required treatment [98].

Mitomycin C has also been used in the upper tract and has been found to be tolerated by patients. Eastman and Huffman reported seven patients with mitomycin C instilled in the intrarenal collecting system through a simple J-ureteral catheter or a percutaneous nephrostomy tube after endoscopic resection of upper tract tumors [99]. No systemic side effects were noted, and there was no evidence of disease progression in six patients. Keeley and Bagley similarly found that mitomycin C could be administered without serious sequelae [100]. They found that higher risk grade II tumors that were either larger or multifocal and treated with adjuvant mitomycin C recurred at the same rate as smaller solitary grade II lesions not treated with mitomycin C after ureteroscopic treatment.

Gupta *et al.* have used half-dose BCG and interferon instilled directly into the ureter via a ureteral catheter in weekly doses over 6 weeks [101]. They noted clearance in those patients with isolated upper tract positive cytology.

Thus, adjuvant therapy with either BCG or mitomycin C has been shown to be feasible, but efficacy has not been demonstrated.

Cost of treatment

The application and the need for endoscopic resection and surveillance for upper tract tumors have raised concerns regarding the costs of this management. Pak *et al.* examined the direct costs of renal-sparing conservative measures versus nephroureterectomy and subsequent chronic kidney disease or endstage renal disease [102]. In a cohort of 57 patients with a minimum follow-up of 2 years, renal preservation was 81% with cancer-specific survival of 94.7%. On examination of Medicare payments, even the worst case scenario of a solitary kidney with recurrences at each follow-up for 5 years versus nephroureterectomy and dialysis for the same period would save over US$250 000. This same savings could alleviate the expense of five cadaveric renal transplantations.

Familial neoplasm of the upper urinary tract

Hereditary nonpolyposis colorectal cancer syndrome (HNPCC) is an autosomal dominant disorder which is characterized by germline mutations in DNA mismatch repair genes. The syndrome is associated with multiple colorectal neoplasms and extracolonic tumors, especially of the endometrium, but also of the breast, ovary, and upper urinary tract. Bladder cancer does not appear to be increased in affected family members [103].

The mutations found in HNPCC can be detected as microsatellite instability (MSI) in some DNA sequences or alternatively as the loss of immunostaining for the specific proteins. In one series, analysis showed MSI in 31.3% of consecutive upper urothelial tract carcinomas, the highest frequency reported in any type of tumor [104]. There is an increased risk of developing TCC of the renal pelvis or ureter in patients with HNPCC. However, there is no increased risk of bladder cancer or renal cell carcinoma. Therefore, there is interest in screening of these patients for upper tract urothelial lesions. Excretory urography has been suggested as one option and voided cytology and urinalysis are other options. Reports on screening for recurrences after endoscopic treatment support the value of these studies but also note the lack of sensitivity [105].

In affected members, upper tract neoplasms tend to occur at an earlier age and can be bilateral. These lesions can be treated as other upper tract tumors have been. A conservative, endoscopic approach even in patients with two functioning kidneys should be considered because of the increased risk of developing additional lesions. Successful ureteroscopic treatment of bilateral ureteral tumors, renal pelvic neoplasms, and ureteral lesions in affected patients as young as 42 years have been reported. Postoperative screening in those patients has been by the routine endoscopic surveillance protocol noted above [106]. The presence of upper urinary tract tumors in patients with a history of colon cancer, especially with other associated primary neoplasms at potentially involved sites, including the breast, ovaries, and pancreas, should be considered for screening for HNPCC. Conservative treatment should be considered as first-line therapy.

Benign neoplasms

Benign urothelial neoplasms are rare in the renal pelvis and ureter. Many individual cases or short series have been reported and include fibroepithelial polyps, inverted papillomas, and hemangiomas, as well as the more commonly noted ureteritis cystica.

Fibroepithelial polyps typically appear in young patients as a smooth pedunculated mass in the upper urinary tract, often occurring at the UPJ. Historically, these lesions have been treated by open surgical resection. However, the availability of small ureteroscopes and appropriate biopsy or resection devices, such as used for TCCs, has permitted ureteroscopic diagnosis and treatment [107–109]. Follow-up after treatment is required only to confirm healing without significant stricture.

Inverted papillomas have also been considered benign lesions, although the association with TCC and the difficult histopathologic diagnosis has raised concern. The most common presentation is with hematuria [110]. However, they can also cause obstruction with hydronephrosis. Endoscopically, they appear as a smooth mucosal-based neoplasm. Often, there is a relatively narrow base encompassing less than one-quarter circumference of the ureter. The lesions lack the papillary configuration of low-grade TCC, but can be confused with a higher grade lesion. Endoscopic biopsy is a crucial diagnostic study. It is particularly helpful to excise the entire lesion [111–113]. Follow-up should be maintained both to confirm the patency of the urinary tract and because of the possible association with new TCC. These neoplasms can be treated adequately ureteroscopically.

Totally endoscopic management of upper tract transitional cell carcinoma

Ureteroscopy constitutes an important facet in the totally endoscopic management of upper urinary tract TCC. Suspicious lesions are visualized and biopsied ureteroscopically and many lesions can be treated ureteroscopically. Larger lesions, which cannot be treated ureteroscopically, may be treated more efficiently by percutaneous nephroscopy with laser or electrosurgical resection. Those that are too large or too extensive, or higher grade, or found through surveillance to be uncontrolled endoscopically, require nephroureterectomy, usually with laparoscopic nephroureterectomy. Surveillance is maintained with cystoscopy and ureteroscopy [114, 115]. Upper urinary tract TCC, therefore, can be managed almost entirely endoscopically in the majority of patients (Table 41.9).

Table 41.9 Totally endoscopic management of upper urinary tract transitional cell carcinoma.

Diagnosis: ureteroscopy
Treatment: ureteroscopic or percutaneous nephrolithotomy
Nephroureterectomy: laparoscopy
Surveillance: ureteroscopy

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CHAPTER 42

Retrograde Ureteroscopic Endopyelotomy for Ureteropelvic Junction Obstruction

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Introduction

Advances in technology and instrumentation have changed the practice of urology, especially over the past decade. One of the areas of major impact has been the treatment of ureteropelvic junction obstruction (UPJO), which is defined as an anatomic or functional impedance of urine flow from the renal pelvis into the ureter [1] (Figure 42.1). This condition can be congenital or acquired, the congenital form being the more common. UPJO, although relatively uncommon, warrants prompt attention to alleviate symptoms and prevent deterioration of renal function. Several factors can play roles in the development of UPJO, including intrinsic aperistalsis of the involved ureteral segment, crossing aberrant vessels causing direct compression of the ureter, renal stone disease, and previous surgical or endourologic manipulation.

The advent of smaller-caliber endoscopes [2], and development of laparoscopic reconstructive techniques, laser technology, and robotics have diversified the treatment options for this condition.

Although the efficacy, and decreased morbidity, hospital stay, and need for analgesia with endopyelotomy have been clearly demonstrated, several issues have still not been completely resolved. Should patients be managed initially by ureteroscopy? What are the exclusion criteria for these endoscopic procedures? What are the relative merits of antegrade versus retrograde approaches? In the era of minimally invasive laparoscopy and robotic-assisted surgery, is there still a role for endopyelotomy?

In this chapter we discuss the technique and results at our institution for retrograde ureteroscopic endopyelotomy for the treatment of UPJO.

History

Several reconstructive procedures have been described for the management of UPJO since Trendelenburg's first description of such a procedure in 1886. Open surgical correction was the only mode of treatment for this condition before the introduction of endoscopic and laparoscopic techniques, and has been considered the gold standard of treatment for this condition, with success rates over 90% [3]. However, associated morbidity is not unusual with open surgery; specifically, there is fistula formation in 2.6% of patients, stricture of the UPJ in 2.4%, and the need for nephrectomy in 3.2% [4].

The present-day endourologic approach to the management of UPJO can be traced back to the original descriptions of Albarran, Keyes, and Davis. Albarran did the first endosurgical repair of the UPJO in 1903, which actually described a ureterotome externe [5]. Keyes performed a similar procedure successfully in 1915 [6]. Both the antegrade and retrograde endopyelotomy follow the concept of Davis's intubated ureterotomy, first described by Davis in 1943. In 1985, Bagley *et al*. reported a combined percutaneous and flexible ureteroscopic approach for the management of an obliterated UPJ [7]. Wickham and Kellet described the first ureteroscopic pyelolysis of the UPJ in 1983 [8], and this was repeated by Inglis and Tolley in 1986 [9]. Thomas

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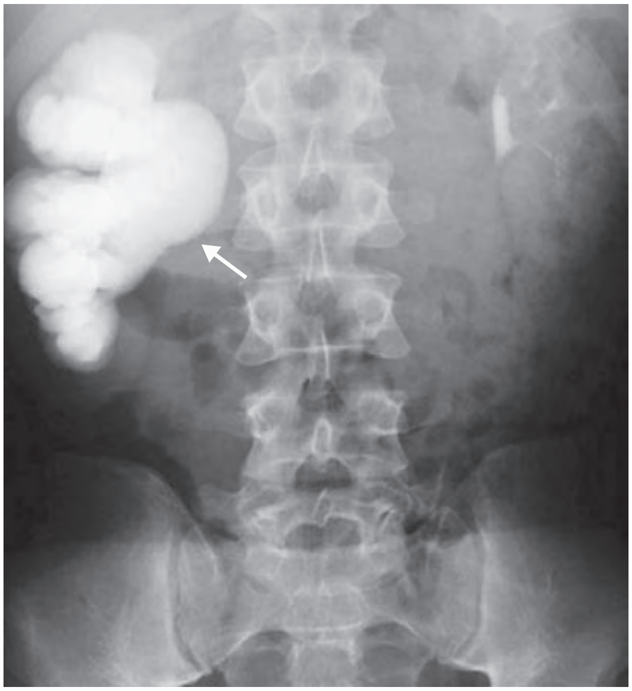

Figure 42.1 Intravenous pyelogram of a right ureteropelvic junction obstruction (arrow).

et al. described their experience of ureteroscopic endopyelotomy in which prestenting was performed to facilitate ureteroscopy in 1996 [10]. A single-setting, one-stage procedure was subsequently described by Soroush and Bagley in 1998 [11].

There are now multiple different options for the treatment of UPJO, including antegrade nephroscopic endopyelotomy, retrograde ureteroscopic endopyelotomy, Acucise™ (Applied Medical, Rancho Santa Margarita, CA, USA), and laparoscopic and robot-assisted pyeloplasty, as well as the traditional open surgical pyeloplasty [12]. As mentioned above, open surgical dismembered pyeloplasty has been considered the gold standard for the treatment of UPJO, with success rates of over 90%. However, many institutions now consider endopyelotomy a possible first-line therapy option for the treatment of this condition [13–16].

Currently, a retrograde endopyelotomy can be performed in three ways: (1) using a rigid ureteroscope and a cold-knife, electrocautery, or holmium laser incision; (2) using a flexible ureteroscope and electrocautery or laser incision; and (3) in rare select cases, using a balloon with a cutting wire (Acucise) [15]. Additionally, an emerging technique of dilation and cold-cut incision with a peripheral cutting balloon, which was originally designed for angioplasty, is currently being investigated [17–19].

Different series have reported success rates for retrograde ureteroscopic endopyelotomy to be in the range of 73–90% [10, 11, 20–24]. As compared with other treatment options, ureteroscopic retrograde endopyelotomy is less invasive, requires less operating room time, enables the procedure to be performed on an outpatient basis or with a very short hospital stay, and is associated with a shorter convalescence period [1, 13, 25–29]. Also, the initial report of ureteral stricture formation because of thermal injury from transmission of the electrocautery current has been eliminated with the use of insulated ureteroresectoscopes and holmium laser fibers [30].

Patient selection and preoperative preparation

The presumptive clinical diagnosis of UPJO can be evaluated and/or confirmed with a renal ultrasound, intravenous pyelogram (IVP), diuretic renal scan, retrograde pyelogram, computed tomography (CT) scan, Whitaker test, or with a combination of these, as is clinically indicated. The renal scan, besides aiding in the diagnosis of a UPJO, gives a quantitative differential renal function, which can be used to choose the best treatment option and, further, to allow for follow-up evaluation of the renal function.

Either a spiral CT angiography or an endoluminal ultrasound is highly recommended to assess for the presence of an aberrant crossing vessel. The UPJ area can also be evaluated ureteroscopically for the presence of pulsations before performing the endopyelotomy incision.

Although ureteroscopic retrograde endopyelotomy is applicable to most patients with UPJO, there are some absolute and relative exclusion criteria. Among the absolute contraindications are patients with active infection and bleeding diathesis.

Patients with concurrent renal calculi and UPJO, and patients with a nephrostomy tube in place, should be treated with an antegrade approach so that both the renal stone and the UPJO can be managed in a one-stage procedure. Patients with a relatively long length of obstruction, usually greater than 2 cm, are best managed either with open surgical, laparoscopic, or robotic-assisted techniques. Patients with ipsilateral differential renal function of less than 20% and severely decreased parenchymal thickness can be given a trial of drainage and re-evaluation [15] or should be offered a laparoscopic simple nephrectomy for a poorly functioning or nonfunctioning kidney. Patients with massive hydronephrosis should be treated with dismembered pyeloplasty, either open surgical, laparoscopic, or robot assisted, because of the need for trimming and reduction of the redundant renal pelvis. Controversy exists with regard to patients with high insertion of the UPJ and crossing vessels. Although once considered a contraindication because of poor results, published series report that the type of ureteral insertion has no significant impact on the outcome of endopyelotomy [24], and that patients with crossing vessels had long-term success with retrograde endopyelotomy [14]. We routinely perform laparoscopic robotic-assisted pyeloplasty in both cases with a high insertion UPJO or a known crossing vessel [12]. Lastly, patients with known intractable stent intolerance should be considered candidates either for an antegrade endopyelotomy or an open pyeloplasty with a nephrostomy tube, and not for ureteroscopic endopyelotomy.

Once the surgeon and patient have decided on the retrograde approach for management of a UPJO, an indwelling ureteral stent is usually placed to drain the obstructed renal unit for 1–2 weeks. This procedure not only drains the obstructed renal unit, but also stabilizes its renal function, dilates and straightens the UPJ, and facilitates subsequent passage of the ureteroscope into the renal pelvis. Above all, preoperative placement of the stent allows evaluation of any degree of stent intolerance and identifies improvement of renal function after drainage.

Informed consent

On the day of the scheduled endopyelotomy, any final questions are answered and an informed consent is obtained after explaining and discussing with the patient the expected outcomes and benefits of the procedure (e.g. improved renal drainage, preservation of renal function, diminished risk of calculus and infection, minimally invasive procedure), its associated risks or complications (bleeding, infection, possibility of conversion to open surgery, recurrence, etc.), and the other minimally invasive treatment options available. Patients are informed that postoperative evaluations may show some residual caliectasis, especially in those with long-standing UPJO.

Step-by-step operative technique

The required instrumentation is listed in Table 42.1.

After either a general or a spinal anesthesia, the patient is placed in the lithotomy position. Caution is taken so that all pressure points are well cushioned, and antiembolic stockings are used in high-risk patients.

With the use of a cystoscope, and under fluoroscopic guidance, a retrograde pyelogram is performed to confirm the length of the UPJO segment, and subsequently a super-stiff guidewire is passed and coiled into the renal pelvis. If the patient had a previously placed indwelling ureteral stent, it is removed and used to pass the guidewire prior to removing the stent. A retrograde pyelogram can assess any resolution of hydronephrosis and can be used as a prognostic indicator.

The next step varies depending on whether the endopyelotomy is done with electrocautery through a ureteroresectoscope or whether a holmium laser is used through a rigid, semi-rigid, or flexible ureteroscope.

Table 42.1 Required instrumentation.

Holmium laser ureteroscopic endopyelotomy

7.5F rigid and/or flexible ureteroscope

200- or 365-μm holmium laser fiber at the following settings:
- 1.5–2.5 J
- 10–15 Hz

Super-stiff guidewire (0.038-inch)

Single-action pump system (Microvasive, Watertown, MA, USA)

Endopyelotomy stent (Microvasive or Applied Medical, Rancho Santa Margarita, CA, USA)

Routine cystoscopy and fluoroscopy set-up

Ureteroscopic endopyelotomy with electrocautery

11.5F ureteroresectoscope (Karl Storz, Culver City, CA, USA; Richard Wolf, Rosemont, IL, USA) (Figure 42.2):
- Insulated electrocautery knife
- Cold knife
- Electrocautery attachments

Single-action pumping system (Microvasive)

Super-stiff guidewire (0.038-inch)

5F open-ended catheter

Endopyelotomy stent (Microvasive or Applied Medical)

Routine cystoscopy and fluoroscopy set-up

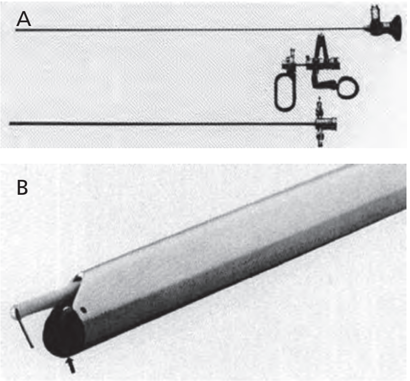

Figure 42.2 (A) 11.5F Ureteroresectoscope with insulated tip. (B) Close-up view of ureteroresectoscope shows insulated cutting electrode in place (arrow).

Holmium:YAG laser ureteroscopic endopyelotomy

A 7.5F self-dilating rigid, semi-rigid, or flexible ureteroscope is passed alongside the super-stiff guidewire using generally accepted ureteroscopic techniques. A balloon dilator can be passed over the guidewire and the ureteral orifice dilated in case of difficulty advancing the ureteroscope within the ureter. If necessary, another guidewire can be passed through the ureteroscope and the narrow area subsequently balloon dilated.

Once at the UPJ, this is first inspected for the presence of any transmitted pulsations. A 365-µm holmium laser fiber, when using a rigid or semi-rigid ureteroscope, or a 200-µm fiber in the case of a flexible ureteroscope, is passed through the working channel of the ureteroscope. At a setting of 1.5–2.5 J and a frequency of 10–15 Hz, the UPJ is incised under direct vision either laterally or posterolaterally to avoid the risk of injuring any unsuspected crossing vessel. The incision is carried on until periureteral fat is seen and the UPJ is wide enough to permit easy passage of the ureteroscope into the renal pelvis (Figure 42.3).

After hemostasis of any venous bleeding is performed, the laser fiber and ureteroscope are removed. The UPJ area is dilated up to 24F using a balloon dilator under fluoroscopic guidance. The concept of balloon dilation of the UPJ is based on Davis's intubated ureterotomy, in which the incised and dilated ureteral fibers regenerate around the ureteral stent over a 6-week period [6] (Figure 42.4).

The balloon dilator is then removed. An endopyelotomy stent is placed under fluoroscopic control, leaving the 14F or 10F end at the UPJ (depending on the stent used) and the 7F end coiled in the bladder (Figure 42.5). Alternatively, an 8F double-J ureteral stent can be left in place. The authors recommend using a ureteral stent one size longer than anticipated to prevent downward migration of the renal coil into the incised UPJ, which may leak into the retroperitoneal space with formation of a urinoma.

An indwelling Foley catheter is placed to drain the bladder for 48 h. This helps to maintain a low pressure in the urinary system and to prevent urinary reflux through the ureteral stent into the incised UPJ, which also may leak into the retroperitoneal space, possibly causing formation of a urinoma.

Ureteroscopic endopyelotomy with electrocautery

A 5F open-ended catheter is passed over the super-stiff wire. The open-ended catheter works as an insulator,

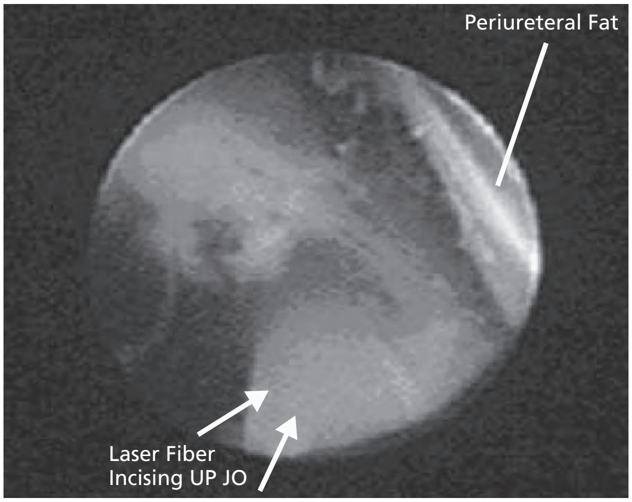

Figure 42.3 Periureteral fat seen after the ureteropelvic junction was incised with a holmium laser. UPJO, ureteropelvic junction obstruction.

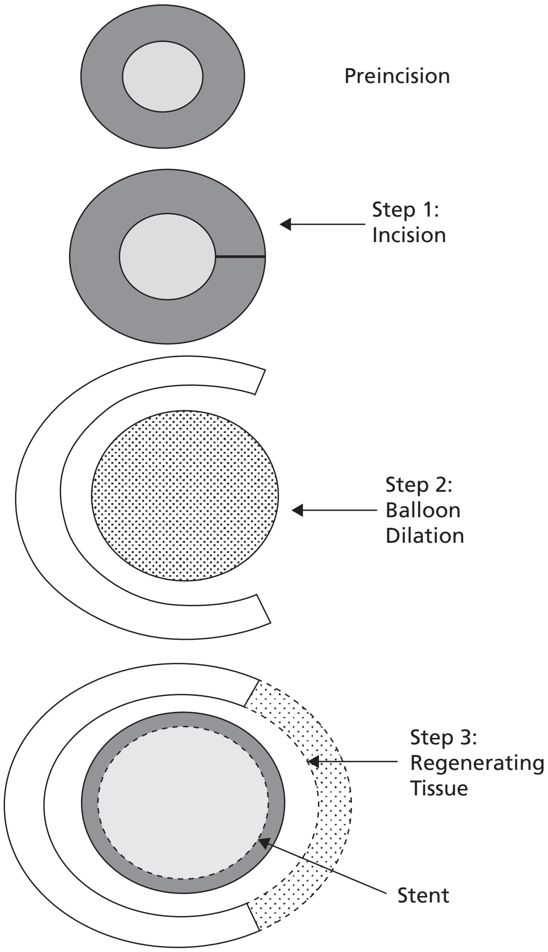

Figure 42.4 Tissue regeneration after incision and balloon dilation.

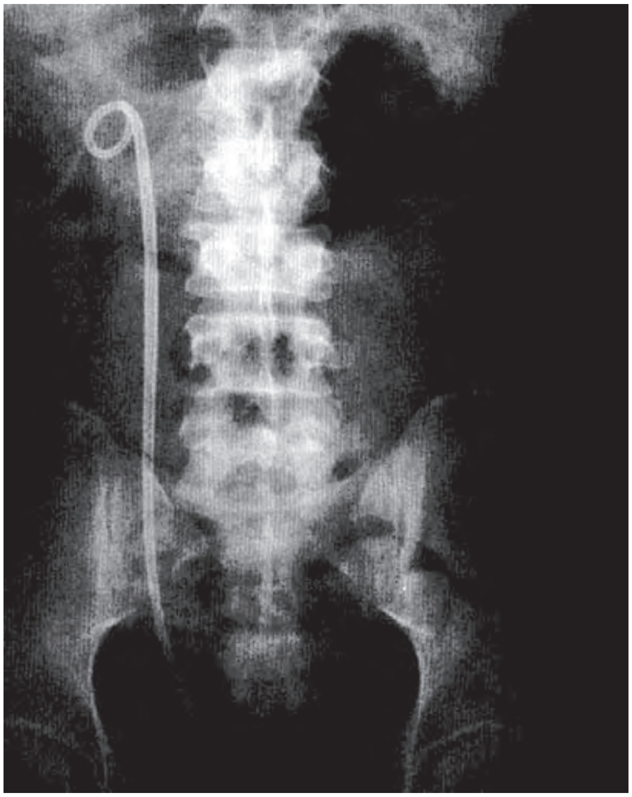

Figure 42.5 Endopyelotomy indwelling stent in place after ureteropelvic junction obstruction incision.

preventing contact with the electrocautery element, and avoiding transmission of current along the length of the guidewire if contact is made. Also, the open-ended catheter may serve to continuously drain the renal pelvis of the irrigant used during the procedure, once the wire is removed.

The ureteroresectoscope is passed directly alongside the insulated guidewire with the cold knife in place. The electrocautery element is right angled and would impede vision if placed during the insertion of the ureteroresectoscope [1]. If there is difficulty accessing the ureteral orifice or the intramural ureter, a balloon dilator can be passed over the guidewire to dilate the area. If there is resistance advancing the ureteroresectoscope along the ureter proximal to the UPJO, a smaller self-dilating ureteroscope can be passed to passively dilate the ureter and to inspect for the cause of the narrow area. If necessary, another guidewire can be passed through the self-dilating ureteroscope and the narrow area is balloon dilated.

Once at the UPJ, the cold-knife working element is exchanged for the electrocautery element. Either water or 1.5% glycine solution is used as the irrigant during electrocautery for incision.

The UPJ is first inspected for the presence of any transmitted pulsations, and then incised laterally, between 8 and 9 o'clock on the right and between 3 and 4 o'clock on the left. Short and shallow strokes should be performed and aggressive and deep incisions avoided. Any bleeding site is controlled by means of spot electrocoagulation. The incision is carried down until periureteral fat is seen and the ureteroresectoscope enters the renal pelvis with ease.

The ureteroresectoscope and the open-ended catheter are removed. The rest of the subsequent steps, balloon dilation, stenting, and Foley catheter drainage, are the same as described above for the holmium:YAG laser endopyelotomy.

Postoperative care

The vast majority of patients are discharged either the same day or within the first 24 h following the procedure. Oral antibiotics, usually quinolones, are given for 3–5 days; oral antispasmodics and/or oral anticholinergics are given as needed in case of irritative bladder symptoms. The Foley catheter is removed, often by the patient, after 48 h. The ureteral stent is removed cystoscopically in 6 weeks.

Diuretic renal scans or IVP are performed 4 weeks after ureteral stent removal. Patients are followed-up with renal ultrasound or renal scan every 4–6 months during the first year and yearly thereafter or as needed.

Success following endopyelotomy is measured by evaluating improvement of the function and drainage of the involved kidney and alleviation of symptoms. After correction of the obstruction at the UPJ, postoperative radiographic images from an IVP or CT scan often show residual caliectasis resulting from long-standing obstruction and dilation that may not completely resolve.

Results

We analyzed the outcome of 139 consecutive patients who underwent retrograde ureteroscopic endopyelotomy at Tulane University Health Sciences Center between 1989 and 2002. These patients included seven pediatric patients, four solitary kidneys, two horseshoe kidneys, and one ptotic kidney.

The average postoperative hospital stay was less than 24 h. Seventy-nine percent of the patients were discharged home on the same day, and 97% of them within 24 h.

Of the 139 patients 32 (23%) required subsequent procedures to treat recurrence of obstruction, showing an overall long-term success rate for retrograde ureteroscopic endopyelotomy of 77%. Fourteen of these patients (10%) required major open or laparoscopic surgical intervention, including nephrectomies for severe hydronephrosis and nonimprovement in renal function in three (2%) cases, emergent nephrectomy for severe bleeding in one (0.7%), dismembered pyeloplasties in eight (5.7%), and spiral flap pyeloplasties in two (1.4%).

Eighteen (12.9%) patients required minor procedures, which included cystoscopy and balloon dilation of the UPJ in 13 (9.3%), repeated retrograde endopyelotomy in four (2.8%), and long-term indwelling stent exchange in one (0.7%). There were no ureteral strictures secondary to manipulation in our series.

After analyzing the failures of treatment in this series, two factors were obviously associated with poor results (no improvement of symptoms, drainage, and function after endopyelotomy): (1) a long-standing obstruction with a decrease in ipsilateral renal function of less than 20% of the total renal function; and (2) a severely dilated renal pelvis, which did not improve on drainage with an indwelling ureteral stent..

After evaluation of these results, we conclude that patients with patulous redundant renal pelvis and borderline salvageable renal function should be considered candidates for alternative treatment modalities, such as open or laparoscopic/robotic pyeloplasty or nephrectomy, rather than endopyelotomy.

Complications

Since its initial description by Young in 1912, retrograde ureteroscopy has come a long way and has gained widespread acceptance as an option for the treatment of multiple pyeloureteric conditions. Further advances in technology have lead to the introduction of smaller-caliber ureteroscopes with the capacity to accommodate accessory instruments necessary to perform diagnostic and therapeutic upper urinary tract procedures.

As with ureteroscopy, the complications and adverse events associated with retrograde ureteroscopic manipulation of the ureter have decreased dramatically in the past two decades. Smaller-caliber ureteroscopes, the advent of laser technology, improved paraphernalia, and, above all, experience in the procedures should be given credit. Although these advances have decreased the need for open ureteral surgery, iatrogenic injury can still occur with the endoscopic technique. Possible iatrogenic complications of ureteroscopy include ureteral perforation, stricture, false passage, ureteral avulsion, bleeding from the ureteral mucosa or adjacent structures, infection, and sepsis. Multiple studies have reported the overall complication rate of ureteroscopy to fluctuate between 1% and 15% [31–33].

The reported incidence of pain, fever, false passage, and urinary tract infection are 5.5%, 1.4%, 0.4%, and 1.6%, respectively, in one large ureteroscopy series [34].

Other complications associated with incision of the UPJ can include bleeding from adjacent aberrant vessels, stent migration through the UPJ incision, and UPJO recurrence. Significant bleeding requiring emergent nephrectomy is another possible complication that justifies the need for vascular or three-dimensional (3D) radiographic studies to identify aberrant vessels. The use of a complete lateral incision at the UPJ helps to prevent injuries to those vessels.

Minor complications of retrograde ureteroscopic endopyelotomy include proximal stent migration, stent intolerance, minor bleeding, and urinary tract infection after manipulation. Most of these complications are alleviated after removal of indwelling ureteral stents. The routine use of antispasmodic and anesthetic drugs after surgery improves tolerance to the stent and decreases complaints from the patient.

Comparison of treatment approaches and conclusions

Multiple endourologic and open surgical techniques are now available for the treatment of UPJO. The choice of technique relies primarily on the urologist's experience with each procedure, available equipment, and the need to perform another concomitant procedure.

Antegrade endopyelotomy requires expertise in percutaneous renal surgery, with detailed knowledge of the intrarenal anatomy and adequate experience in "real-time" 2D fluoroscopic imaging. This is the preferred technique when treating concomitant intrarenal calculi, but it is also associated with a larger potential for complications and morbidity. The occurrence of pneumothorax, adjacent organ trauma (i.e. bowel, spleen, liver), and hydrothorax are possibilities that need to be explained to the patient prior to the surgery. Antegrade and retrograde endopyelotomy share the potential for hemorrhage from injury to aberrant crossing vessels; however, antegrade access may also be associated with hemorrhage from the percutaneous renal tract and with a higher risk of infection owing to external urinary drainage through the percutaneous nephrostomy tube.

Acucise retrograde endopyelotomy relies on fluoroscopic imaging and not on direct visualization during cutting of the UPJ. High-quality fluoroscopic imaging is critical for optimal electrode placement. Short-term success rates of this procedure have been comparable to those obtained with retrograde ureteroscopic endopyelotomy and range from 66% to 84% [35]. Extreme caution should be exercised when using this technique in the presence of aberrant crossing vessels. Preoperative CT scan with angiographic phase and 3D reconstruction has been shown to be adequate to collect information regarding periureteral vasculature at the level of the obstruction [36]. Incision at the lateral position of the UPJ should minimize the risk of vascular injury while performing this procedure. Use of this technique has dramatically decreased because of lower success rates with long-term follow-up.

Multiple different indwelling stents can be used to maintain patency of the UPJ after an endopyelotomy. At our institution we use an 8F double-J ureteral stent with postoperative results similar to those obtained with endopyelotomy stents. It is always important to use an indwelling stent one size longer than anticipated in order to avoid downward migration of the stent that could compromise endopyelotomy healing.

It is our belief that retrograde ureteroscopic endopyelotomy provides a safe and adequate first-line treatment for patients suffering from UPJO. With the advent of smaller scopes and devices, this technique has evolved to include larger children as possible patients. Adherence to strict endourologic principles and direct visualization makes retrograde ureteroscopic endopyelotomy a safe and effective treatment modality. Furthermore, this procedure has a short learning curve and can be performed in almost all general hospitals where ureteroscopy is performed.

Lastly, this procedure should always be part of a urologist's treatment armamentarium, because patients who have failed laparoscopic, robotic, or open surgical pyeloplasty can be managed with ureteroscopic retrograde endopyelotomy.

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CHAPTER 43

Mid-Ureteral Obstruction

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Introduction

Advances in both diagnostic and therapeutic endoscopy have resulted in a paradigm shift away from open surgery to minimally invasive management of ureteral obstruction. The causes of ureteral obstruction are numerous, often occurring at any location along the length of the ureter. This chapter focuses primarily on the etiology, evaluation, indications for intervention, as well as the endourologic and laparoscopic management of obstructing lesions in the middle third of the ureter.

Etiology

A proper understanding of ureteral anatomy is essential (see also Chapter 33). To facilitate ureteral description, the ureter can be divided into upper, middle, and lower segments. The middle third of the ureter comprises the segment that crosses anterior to the sacrum. It is also the segment that passes over the iliac vessels. Mid-ureteral obstruction is a common presentation to endourologists. Ureteral obstruction can be characterized as inflammatory, malignant, or congenital, e.g. tuberculosis and schistosomiasis cause significant ureteral inflammation during the active infection, with subsequent fibrosis commonly involving the distal half of the ureter [1, 2]. Other benign causes of ureteral strictures include prior radiation therapy, inflammatory abdominal aortic aneurysm, endometriosis, and regional trauma, including iatrogenic injury from previous abdominal or pelvic surgery [3, 4].

The causes of ureteral obstruction can also be divided into extrinsic (compressive), intrinsic (involving the ureteral wall), and intraluminal. Examples of extrinsic causes of obstruction include retroperitoneal fibrosis, pelvic lipomatosis, obstetric and gynecologic causes (pregnancy, tubo-ovarian abscess, retroperitoneal endometriosis, ovarian mass lesions), and vascular causes (abdominal aortic and iliac artery aneurysms, vascular graft compression, gonadal vein thrombophlebitis, circumcaval ureter). Intrinsic causes include fibrosis and stricture, ureteral wall endometrioma, and submucosal foreign body with associated granulomatous reaction (e.g. submucosal stone; Figure 43.1). Examples of intraluminal causes of obstruction include papillary urothelial carcinoma (Figure 43.2), an impacted ureteral calculus, sloughed papilla due to papillary necrosis, and inflammatory mass lesions, which can be either fungal or bacterial in origin.

The basic tenet with regard to treating an intraluminal obstruction is to remove the lesion and allow the local reaction to resolve over time. Persistent obstruction thereafter often reflects an intrinsic ureteral wall process, the most common of which is ureteral wall fibrosis or stricture. Other causes of intrinsic ureteral wall obstruction are listed in Table 43.1. Malignant causes such as urothelial carcinoma can appear on contrast-based imaging as a radiolucent filling defect within the lumen with the classic goblet or Bergman's sign. The majority of upper urinary tract urothelial tumors are papillary, like those encountered in the bladder, with a significant percentage of the higher grade lesions having an

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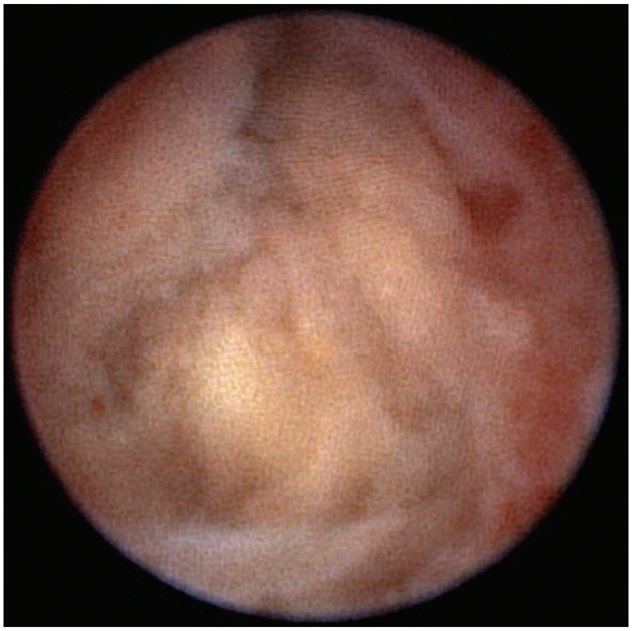

Figure 43.1 Submucosal stone. Patient presented post ureteroscopy with evidence of hydronephrosis on postoperative ultrasound.

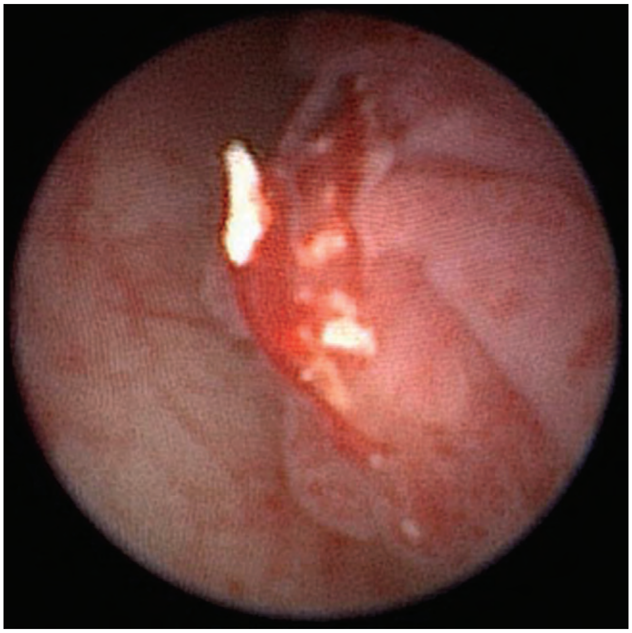

Figure 43.2 Papillary urothelial tumor with adherent calcification. Patient presented with flank pain and gross hematuria. CT imaging revealed hydronephrosis and hydroureter down to the level of the tumor in the mid ureter.

Table 43.1 Etiology of ureteral stricture.

Inflammatory/infectious
Impacted ureteral calculus
Radiation therapy
Inflammatory abdominal aortic aneurysm
Endometriosis
Tuberculosis
Schistosomiasis
Iatrogenic
Postsurgical and endoscopic instrumentation
Malignant
Transitional cell carcinoma
Cervical cancer

intrinsic, invasive component involving the ureteral wall (see Video 43.1A). Secondary or metastatic tumors (e.g. cervical, prostate, ovarian, breast, and colon) can involve the ureter and cause high-grade obstruction. As opposed to ureteral strictures that are the product of inflammatory, infectious, or iatrogenic causes, those associated with or the product of treatment for a malignancy (i.e. radiation fibrosis) are the most challenging to treat.

The incidence of ureteral strictures in the general population is unknown, but the presence and treatment of ureteral calculi are significant risk factors. Those patients with long-standing ureteral obstruction from an impacted ureteral calculus are at high risk for subsequent stricture after successful lithotripsy. Roberts *et al.* reviewed 21 patients with impacted ureteral stones and found that stones impacted for greater than 2 months were associated with a 24% incidence of stricture formation [5]. Endoscopic management of ureteral calculi may also lead to stricture formation. Ureteroscopic lithotripsy's origins began with pioneering work in the early 1980s. These centers employed large-caliber (>12F) rigid ureteroscopes, often requiring significant dilation for access, combined with traumatic lithotrites like electrohydraulic probes. The risk of perforation and subsequent stricture with these early techniques was an unacceptably high 10%. Advances in materials and endoscope design led to smaller and flexible endoscopes with improved optics. The addition of the small diameter, actively deflectable, flexible ureteroscope and laser lithotrite significantly decreased tissue trauma. For these reasons, the incidence of ureteral stricture formation from ureteroscopic instrumentation has dramatically decreased to less than 1% [6, 7]. Dretler and Young were the first to describe the entity of a "stone granuloma" as embedded particles of calcium oxalate associated with macrophages and foreign body giant cells in the wall of the ureter [8]. This is a possible, although rare, complication of ureteroscopy where partial ureteral disruption during ureteral stone fragmentation results in stone material being embedded in the ureteral wall, causing surrounding fibrosis and ureteral obstruction (see Videos 43.2A and B).

Evaluation

The evaluation of an obstructed upper urinary tract often begins with sonography. Hydronephrosis and proximal ureteral dilation are often the limits of grayscale sonographic imaging. Color Doppler enhancement is useful in defining renal arterial perfusion, arterial resistive indices, and also the presence of ureteral flow jets in the bladder. Computed tomographic (CT) urography is the most common next imaging study. Three-phase CT imaging, with noncontrast, perfusion, and then drainage phases is often essential in defining the location and etiology of ureteral obstruction. Delayed CT imaging is useful in differentiating intrinsic ureteral lesions from those caused by external compression. It is essential to perform sufficiently delayed imaging to visualize the entire ureter, in an attempt to clarify the exact location and cause of the obstruction. When CT imaging does not clearly define the cause of obstruction, either from poor excretion or impaired renal function from obstruction, then direct instillation in either an antegrade or retrograde fashion (i.e. retrograde ureteropyelography) is particularly useful in defining the length, location, and nature of ureteral obstruction.

If the mid-ureteral obstruction has been chronic in nature and there is evidence of poor renal function of the ipsilateral kidney on CT, then a nuclear medicine renogram (e.g. MAG3) should be performed to evaluate differential function, as this may affect treatment options. Endourologic therapies generally require marginal reversible renal function of the ipsilateral kidney in order to obtain reasonable ureteral patency rates with endoscopic intervention [9]. It is believed that urine flow through the incised or repaired segment of ureter is required in order to maintain patency. A diuretic can be administered during the renogram to assess for functional obstruction as well, and is particularly useful during surveillance post surgical intervention.

Ureteroscopy is commonly performed to define the nature and location of ureteral obstruction. Endoscopic biopsy is commonly performed when a malignant etiology is being entertained (see Video 43.1B and C). Endoluminal ultrasound, ultrasound imaging from within the ureter with small-caliber high frequency probes, can be employed to direct therapy and characterize a stricture [10]. The advantage of endoluminal ultrasound is particularly evident during endoureterotomy where it can be used by the surgeon to obtain realtime images of surrounding structures, directing the incision away from adjacent vasculature. Intraluminal sonography has also been useful in defining hidden and submucosal calculi, which can cause severe granulomatous local reaction with resultant ureteral fibrosis [11]. Differentiating ureteral edema and inflammatory changes from fibrosis and ureteral scarring can significantly change treatment. When the endoscopic appearance cannot differentiate an obstructing lesion, specialized imaging, including intraluminal sonography, is often useful in directing treatment.

Indications and contraindications for intervention

Mid-ureteral obstruction can reflect many disease states. It is important to differentiate lesions preoperatively to obtain the best surgical outcome. Improving ureteral drainage with surgical intervention can be achieved with a variety of techniques. There are, however, general principles on how and when to intervene surgically. For patients who present with urosepsis and evidence of ureteral obstruction, prompt decompression of the obstructed renal unit should be performed, either by retrograde ureteral stent insertion or percutaneous drainage of the pyelocalyceal system. Definitive management of the mid-ureteral obstruction should then be deferred until the patient recovers clinically from the acute septic episode, the urine culture normalizes post antibiotic therapy, and the inflammatory reaction noted with the acute infectious process subsides.

General contraindications to endourologic intervention are identical to those noted with open surgical intervention employed for ureteral stricture disease (e.g. uncorrectable bleeding diathesis, etc.) Relative contraindications for ureteroscopic incision, for example, include active urinary tract infection versus bacterial colonization, long, dense ureteral strictures, and poor ipsilateral renal function. For patients with long strictures, open or laparoscopic surgical intervention is often superior as endourologic management of strictures greater than 2 cm in length is associated with high recurrence rates.

Endourologic options for intervention

Minimally invasive endourologic interventions are commonly employed once a ureteral obstruction is defined. Balloon dilation and ureteral stenting are employed ubiquitously for lesions collectively termed "ureteral strictures." The relatively high success of these interventions underscores the likelihood that many of these obstructing lesions are inflammatory and most benefit from minor interventions to help facilitate healing. True strictures, a white circular band of scar tissue without lining mucosa, require definitive intervention by either ureteroscopic incision or laparoscopic reconstruction employing viable tissue for repair akin to the historic open surgical repair.

Ureteral stent placement

Commonly, ureteral obstruction can be acutely managed with ureteral stent placement, particularly those secondary to intrinsic ureteral lesions. Extrinsic ureteral obstruction can also be addressed acutely with a firm, larger diameter stent. Percutaneous nephrostomy drainage can also be employed to obtain proximal drainage, especially when retrograde stenting is unsuccessful or inadequate. Chronic stenting, requiring periodic stent changes, is reserved for patients who are deemed poor surgical candidates for definitive repair, those with an overall poor prognosis, or when definitive intervention is deemed high risk. Chronic stenting in the setting of extrinsic ureteral obstruction may, however, lead to slow deterioration in renal function, since adequate drainage may be only temporary [12, 13]. Placement of two large diameter adjacent stents to maintain ureteral patency when a single standard stent has not provide adequate drainage is useful in patients with dense, compressive retroperitoneal fibrosis.

Retrograde ureteral balloon dilation

Retrograde ureteral balloon dilation of an obstructing lesion is commonly performed. With the application of angiographic dilation balloons for this purpose in the early 1980s, the technique of balloon dilation and temporary ureteral stenting became an accepted mode of treatment for ureteral obstruction. Success with balloon dilation varies, based in large part on the underlying etiology of the ureteral obstruction: inflammatory lesions respond well, while long fibrotic segments often require repetitive sessions before ultimately undergoing another definitive treatment.

Indications to intervene with retrograde balloon dilation of a ureteral lesion include functionally significant obstruction where access across the ureteral segment can be obtained using transurethral techniques. The procedure begins with retrograde contrast-based imaging. A pyelogram is performed fluoroscopically to help delineate the site and length of the stricture. Various guidewires, some hydrophilic coated, are employed with a 5F braided ureteral catheter under fluoroscopic guidance to traverse the obstructed segment. This is usually accomplished by placing the open-ended catheter up to the level of the obstruction, and through which the guidewire is directed to gain proximal access. Once access has been obtained proximal to the stricture, the ureteral catheter can be advanced over the guidewire through the obstructed segment. The guidewire can then be exchanged with the catheter for a stiffer Amplatz variety if the ureter requires straightening, for example. The ureteral access catheter is then exchanged over the guidewire for a 4-cm long, 5–8-mm balloon dilation catheter, positioned under fluoroscopy across the ureteral segment using radio-opaque markers as guides (Figure 43.3A). Balloon inflation employing radio-opaque contrast is then performed (Figure 43.3B). A ureteral stent is then inserted over the guidewire with its position verified fluoroscopically. Follow-up imaging is performed 4–6 weeks following stent removal to assess for adequate drainage.

Occasionally, obtaining guidewire access beyond the stricture under fluoroscopic guidance as described above is unsuccessful. In such cases, passage of a guidewire under direct visualization can be accomplished ureteroscopically. The importance of diagnostic ureteroscopy in this setting cannot be overstated. Once guidewire access is obtained in this fashion, the ureteroscope is then withdrawn and the procedure is continued as described previously.

Percutaneous nephrostomy and antegrade balloon dilation

There are times when retrograde access across an obstructed ureteral segment is unsuccessful and thus not feasible. In these cases, antegrade intervention to ensure renal drainage and to gain access to the ureter from this approach is essential. The patient is positioned laterally or prone, and under ultrasound guidance, percutaneous guidewire access to the collecting system is obtained. As with retrograde ureteral access, a hydrophilic guidewire is advanced into the pyelocalyceal system under fluoroscopic guidance. A braided angiographic catheter, like the Kumpe catheter, is then advanced over the guidewire and a nephrostogram performed to delineate the collecting system anatomy and identify the site of ureteral obstruction. The steerable angiographic catheter is then employed to direct the hydrophilic guidewire down the ureter under fluoroscopic guidance. The catheter is then advanced over the guidewire and both are manipulated through the obstructed segment. If access through the obstructed ureteral segment is unsuccessful, the nephrostomy tract can be dilated to facilitate antegrade diagnostic ureteroscopy. After the percutaneous tract is dilated to a diameter that will accept the endoscope, the flexible ureteroscope is then advanced over a guidewire in an antegrade fashion to allow direct visualization of the ureter. Small-diameter, 12F balloon dilators can be passed through the working channel of the flexible ureteroscope and facilitate dilation under both visual and fluoroscopic guidance. These small-diameter (12F outer diameter, 3F sheath diameter), low-pressure balloon dilators that can be passed through the flexible ureteroscope are only useful to assist in endoscope access and have little value in definitively treating a dense stricture. Antegrade balloon dilation and ureteral stenting over a

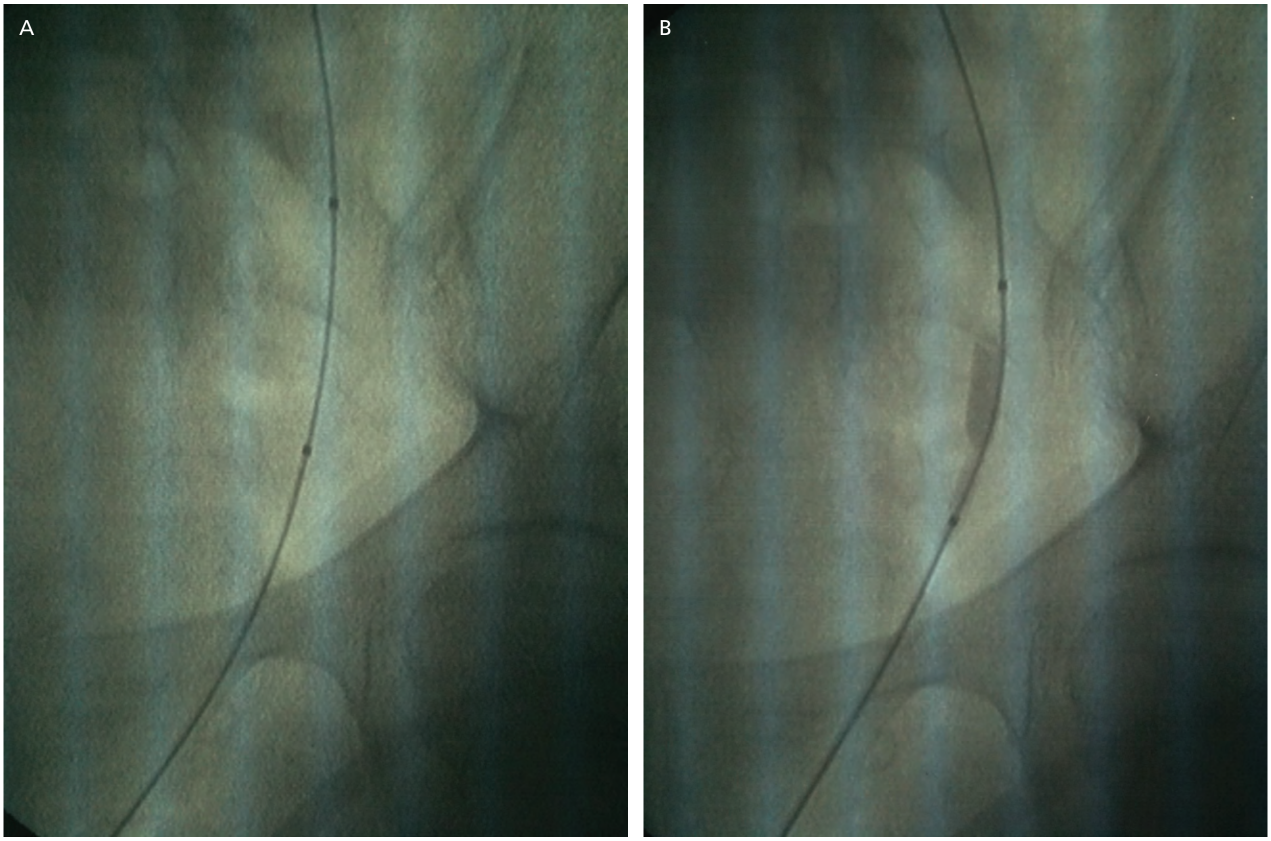

Figure 43.3 (A) Insertion of a balloon dilation ureteral catheter with radio-opaque markers at the level of the ureteral stricture. (B) Inflation of the balloon with contrast demonstrates a "waist" at the level of the stricture.

guidewire is otherwise analogous to the retrograde approach. A nephrostomy tube is then inserted to ensure renal drainage. A follow-up nephrostogram is obtained within the first few days postoperatively to ensure adequate internal drainage before removing the nephrostomy tube. Alternatively, a nephroureteral stent can be inserted at the end of the procedure and the external component subsequently capped to facilitate internal drainage.

Results of balloon dilation

Balloon dilation alone has moderate success rates in treating ureteral obstruction, but generally requires repeat dilations. Initial reports employing balloon dilation of ureteral strictures suggested that outcomes were better when the strictures were anastomotic (i.e. postreconstructive procedure) and short in length [14–16]. More recent review of the literature suggests that the success rates of balloon dilation of ureteral strictures is noted in approximately 50% of all who present with ureteral obstruction, where results were best in patients with iatrogenic, nonanastomotic strictures, such as those following endoscopic instrumentation [17]. Ravery *et al.* found a 40% success rate using retrograde balloon dilation for inflammatory strictures at a mean follow-up of 16 months [18]. In a series of 114 patients with a minimum of 2-year follow-up, Richter *et al.* found higher success rates with balloon dilation for patients with relatively short ureteral strictures [19]. The authors also noted the significance of an intact vascular supply on success rates of balloon dilation. For longer ureteral strictures or those associated with compromised blood supply, the authors recommended performing an endoureterotomy as an alternative to balloon dilation, given the higher success rates with an incisional approach [19]. Interestingly, in experimental models, Nakada *et al.* demonstrated longitudinal incisions created by balloon dilation that were similar to those seen with formal endoureterotomy, possibly explaining the success seen with balloon dilation in managing some ureteral strictures [20].

Endoureterotomy

An endoureterotomy refers to a longitudinal endoluminal incision of the ureter and is a logical extension of balloon dilation for minimally invasive management of ureteral stricture disease. Similar to balloon dilation, access across the strictured segment of ureter is required and this can be obtained either in a retrograde or an antegrade fashion. Retrograde access is usually preferred since it is less invasive. An endoureterotomy is preferably performed under direct vision using a ureteroscope rather than fluoroscopically using the hot wire cutting balloon catheter, given the close proximity of the common iliac vessels. Postoperative follow-up using a combination of renal ultrasound, intravenous pyelography, and diuretic renography may be performed to detect most late failures [9].

Retrograde ureteroscopic approach

The procedure begins with a retrograde pyelogram to identify the location and length of the stricture. As described previously, access is obtained across the strictured segment using either a floppy-tipped guidewire or hydrophilic glidewire. If passage of a wire is unsuccessful under fluoroscopic control alone, a flexible or semi-rigid ureteroscope can be advanced to the level of obstruction and an attempt at passing a wire through the ureteroscope under direct vision can be performed. The ureteroscope is then withdrawn, leaving the wire in place as a safety wire. The ureteroscope is then advanced beside the wire to the level of the stricture.

Prior to performing the endoureterotomy, it is critical to be aware of the blood supply to the particular segment of ureter that is involved. The direction of the endoureterotomy incision depends on the level of the ureter that is strictured. In general, lower ureteral strictures are incised in an anteromedial direction to avoid the iliac vessels. Upper ureteral strictures are incised laterally or posterolaterally, thereby avoiding the great vessels [21]. As mentioned previously, endoluminal ultrasound has been described to obtain realtime imaging of the surrounding periureteral vasculature to minimize the risk of bleeding at the time of endoureterotomy [22].

The endoureterotomy incision can be performed using a cold knife, a cutting electrode, or a holmium laser [23–25]. Regardless of the method chosen, the incision is made from the ureteral lumen out to periureteral fat in a full-thickness fashion. The endoureterotomy incision is continued proximally and distally to encompass 2–3 mm of normal ureteral tissue. Commonly the ureteral segment is balloon dilated post incision to help verify completion. Once the endoureterotomy incision is completed, an internal stent is placed over the safety wire. Larger diameter stents (10–14F) are preferred because they have been associated with improved results [9, 26]. Wolf *et al*. also found benefit in the injection of triamcinolone ureteroscopically after endoureterotomy. Thus, corticosteroids and other biologic response modifiers may have a role in the future in managing select strictures [9].

Reported results for ureteroscopic endoureterotomy using the cold knife, electrocautery, or holmium laser have been described in the literature. Eshghi and Lifson reported their results of cold-knife endoureterotomy in 89 patients with an overall success rate of 95% for initial treatment and 98% for repeat procedures [27]. In their study, no complications were encountered using this technique. Franco *et al.* reported a 100% success rate using cold-knife endoureterotomy in six patients with ureteral strictures, but with short follow-up of 3–8 months [28]. Yamada *et al*. treated 19 patients with a mean follow-up of 18 months and found an 85% success rate with cold-knife incision [24]. In a review of 36 ureteral strictures treated with endoureterotomy using electrocautery, Thomas reported a 64% success rate, with better results in patients with strictures less than 1.5 cm in length (80% success rate) compared with longer strictures (27% success rate) [29]. Previous radiation treatment also reduced success rates to 33%. In their review of electrocautery incisional treatment of ureteral strictures, most of which were secondary to schistosomiasis, Ghoneim *et al*. were successful in four of 12 patients [30]. Singal *et al*. reported a success rate of 76% using the holmium:YAG laser for endoureterotomy, with five of their 21 patients failing treatment [31].

Cautery wire balloon incision

Cautery wire balloon incision was reported by Chandhoke *et al*. in 1993 for the treatment of ureteropelvic junction obstruction and ureteral strictures [32]. This catheter was developed to simplify endopyelotomy and address the concern of ureteral stricture formation following retrograde endopyelotomy when larger diameter rigid ureteroscopes were used in the past [33]. As previously described, when performing this procedure, having safety wire access across the strictured segment is necessary prior to making the incision under fluoroscopic control. The cautery wire balloon can be inserted either in a retrograde or antegrade fashion and positioned appropriately using the radio-opaque markers. Again, the choice of location of the incision depends on the segment of ureter involved in order to avoid the blood supply to the ureter. The incision should be posterolateral in the proximal ureter and anteromedial in the distal ureter. Cautery wire balloon incision under fluoroscopy is not recommended in the mid ureter given the close proximity of the common iliac vessels to the ureter at this location. Success rates utilizing this technique have been described in the literature and, similar to other endourologic techniques, length and vascularity of the involved segment are critical factors in determining success rates [9, 33, 34]. Preminger *et al*. conducted a multicenter trial evaluating 49 patients and reported a 55% patency rate with a follow-up of 8.7

months [35]. With the advances in the design and miniaturization of current ureteroscopes, which have resulted in a reduction in ureteral stricture rates, cautery wire balloon incision under fluoroscopic control has largely fallen out of favor.

Antegrade approach

If the retrograde approach under direct vision is unsuccessful, an antegrade approach may be employed. Nephrostomy tube drainage is established and any infection or renal insufficiency allowed to resolve prior to proceeding with definitive incision of the ureteral stricture. The percutaneous tract is dilated to a size large enough to allow a working sheath through which a flexible ureteroscope may be passed. The procedure is then performed in an analogous fashion to that described for the retrograde approach.

Combined retrograde/antegrade approach

In rare situations, a ureteral stricture is associated with complete ureteral obstruction through which a guidewire cannot be passed in either a retrograde or antegrade fashion, thereby preventing balloon dilation or ureteroscopic endoureterotomy. A combined retrograde/antegrade approach has been described to manage such cases [25, 36–38]. Simultaneous retrograde and antegrade pyelogram is performed to identify the obstructed ureteral segment radiographically (Figure 43.4A). Ureteroscopes are then advanced both in an antegrade and retrograde fashion simultaneously to the obstructed segment (Figure 43.4C). This is confirmed fluoroscopically and the two ureteroscope ends are placed in line with one another (Figure 43.4D). A guidewire is then passed through one ureteral end, through-and-through to the other lumen, using a combination of fluoroscopy and direct visual control. If this is unsuccessful, a "cut-to-the-light" technique can be employed, whereby the ureteral segments are aligned as closely as possible using fluoroscopic and endoscopic control. The light source of one of the ureteroscopes is turned off and, using the light source of the other ureteroscope as a guide, an incision is made to restore ureteral continuity. A guidewire is then passed across the area incised to obtain through-and-through access (Fig. 43.4E). A stent is then inserted and left in place for 8–10 weeks to allow the area to heal. Endoscopy should be performed at the time of stent removal to re-evaluate the strictured area and determine if further endourologic maneuvers are required. Regular follow-up should be performed using a combination of renal ultrasound, intravenous urography, or nuclear renography to evaluate for stricture recurrence.

Success rates of combined retrograde/antegrade approaches, similar to other endourologic interventions, are inversely related to the length of the stricture. Knowles *et al*. reported a 90% patency rate in 10 patients who were treated for obliterated distal ureteral segments at 36 months of follow-up, of whom three required the combined approach [38].

Laparoscopic surgical repair

Prior to surgical repair of a ureteral stricture, it is important to conduct an evaluation of the nature, location, and length of the involved segment of ureter. This can be accomplished by performing a contrast imaging study: intravenous urogram, antegrade nephrostogram, or retrograde pyelogram, depending on the clinical circumstances. Ancillary studies, such as nuclear renography to assess renal function and ureteroscopy to define tissue viability and to help rule out upper tract carcinoma, should be performed depending on the clinical situation. Intraluminal sonography has an adjunctive role and has been employed to define the nature of a ureteral stricture including submucosal calculi, as well as periureteral structures including directly adjacent vasculature [10, 22]. Based on the results of these investigations, appropriate surgical intervention can then be planned and implemented.

Laparoscopic ureterolysis

Retroperitoneal fibrosis and certain gynecologic lesions (e.g. endometriosis) are among the more common benign conditions associated with extrinsic obstruction of the ureter. Ureterolysis is effective for correction of ureteral obstruction in 90% of patients with retroperitoneal fibrosis [39]. When open surgical intervention is employed, it may be associated with significant morbidity in up to 60% of cases [39]. With the development of laparoscopic techniques for ureterolysis, the morbidity of the procedure has been reduced. Elashry *et al*. compared six patients undergoing unilateral laparoscopic ureterolysis for extrinsic ureteral obstruction to seven undergoing open unilateral ureterolysis for similar pathologic conditions [39]. Laparoscopic ureterolysis was associated with less intraoperative blood loss and need for parenteral pain medication, and significantly shorter hospital stay and convalescence than open surgery. Operative time was only marginally longer in the laparoscopy group (255 vs 232 min). Excretory urography and/or renal scan showed improved renal function and relief of obstruction in all patients in this study.

Laparoscopic ureterolysis often begins with cystoscopic placement of a ureteral stent. The patient is then placed in the lateral decubitus position, pneumoperitoneum is obtained, and the laparoscopic ports are placed.

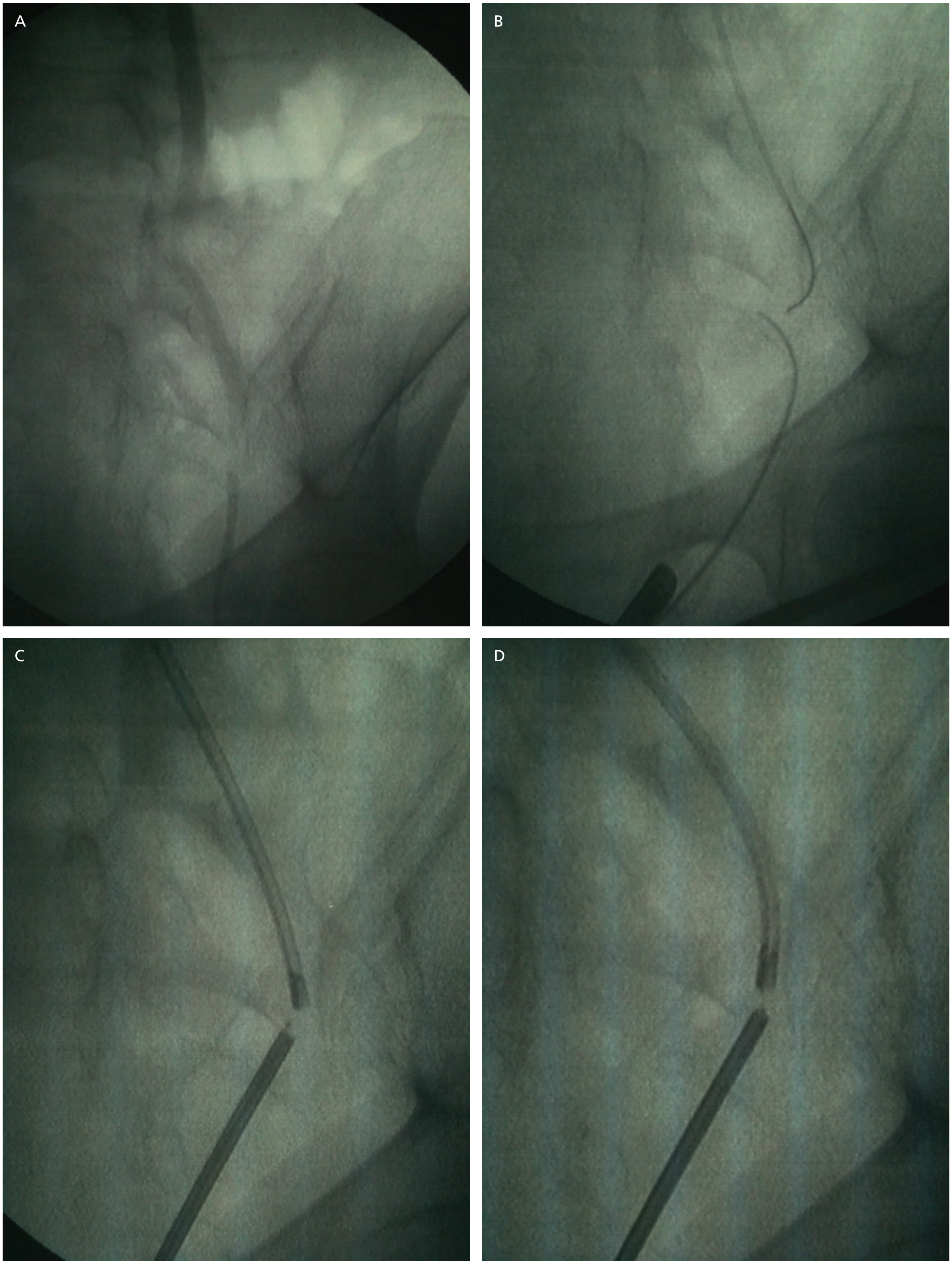

Figure 43.4 (A) Simultaneous antegrade and retrograde pyelogram defines a 1-cm obliterated ureteral segment. (B) Antegrade and retrograde attempts at obtaining guidewire access across the strictured segment under fluoroscopic control proved unsuccessful. (C) Simultaneous antegrade and retrograde ureteroscopy is performed. (D) The two ends of the ureteroscopes are lined up under fluoroscopic guidance and a “cut-to-the-light” technique is employed. (E) Access across the strictured segment is obtained in a retrograde fashion with a guidewire following the “cut-to-the-light” technique, which re-establishes ureteral continuity.

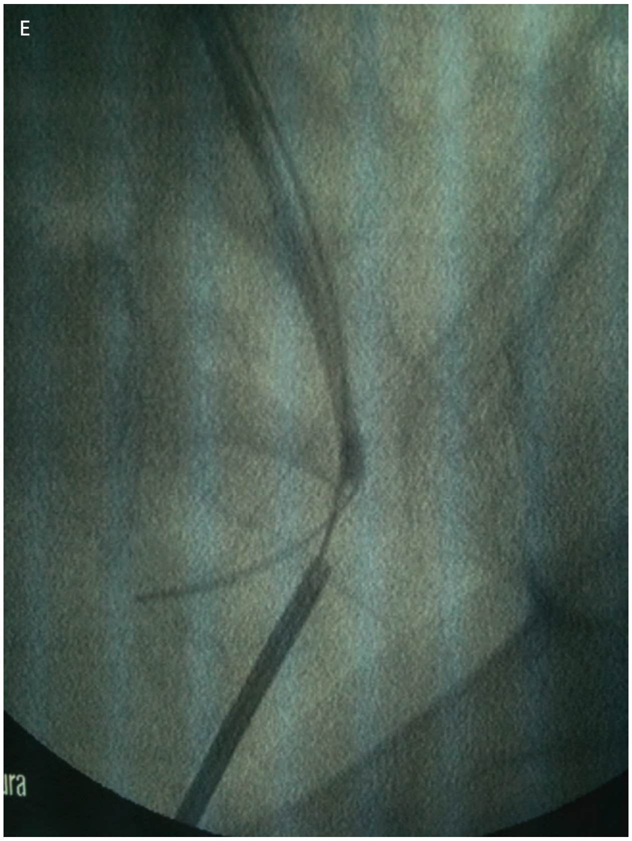

Figure 43.4 *Continued*

For mid-ureteral involvement, using four or five port sites has been described: a 12-mm umbilical or paraumbilical port, 5-mm subcostal upper midclavicular line port, 12-mm lower midclavicular line port below the umbilicus, 12-mm port off the 12th rib along the upper anterior axillary line, and 12-mm port at the umbilicus along the lower portion of the anterior axillary line [39].

The peritoneum is incised along the line of Toldt and extended caudally over the iliac vessels and medial to the medial umbilical ligament. The colon is reflected medially and the entrapped ureter identified with the indwelling stent acting as a guide. Meticulous dissection is performed to mobilize the ureter, freeing it from adjacent structures. Similar to the open surgical technique, a vessel loop can be placed around the ureter to facilitate gentle traction during mobilization. Dissection is carried out proximally and distally to healthy nonfibrotic tissue. A biopsy of the retroperitoneal fibrotic process can be helpful if clinically indicated. Once the ureter is freed from the retroperitoneal fibrotic process, it is positioned into the peritoneal cavity by reapproximating the previously incised edges of the posterior peritoneum using standard laparoscopic intracorporeal suturing techniques with 2-0 absorbable suture. Care should be taken to avoid iatrogenic ureteral obstruction or angulation. Placing an omental wrap is helpful, but is optional, and is based in part on the quality of this structure and the extent of intraperitoneal adhesions. Postoperative follow-up should include early imaging, at which time the ureteral stent can be removed. Serial imaging postoperatively should be performed to ensure long-term patency.

Laparoscopic ureteroureterostomy and ureterocalicostomy

Ureteroureterostomy is most appropriate for short strictures involving either the upper or mid ureter. Only short defects should be managed by end-to-end ureterostomy, as longer strictured segments may result in tension on the anastomosis with potential recurrence of obstruction. Determination of whether enough ureteral mobility can be achieved to obtain a tension-free ureteroureterostomy anastomosis is often an intraoperative decision. Long-term success with a tension-free, watertight ureteroureterostomy is well over 90% [40].

Ureteroureterostomy has been performed using both an open or laparoscopic approach. The laparoscopic technique, albeit endoscopic, follows the tenets of open surgical repair, creating a tension-free spatulated anastomosis. Nezhat *et al*. first reported laparoscopic management of an obstructed ureter secondary to ureteral endometriosis [41]. The obstructed ureteral segment was resected and the ureteroureterostomy was performed laparoscopically over a ureteral stent. In a retrospective review involving eight laparoscopic ureteroureterostomy patients, Nezhat *et al*. found seven patients to have a patent anastomosis, although follow-up was relatively short, ranging from 2–6 months [42]. Laparoscopic ureteroureterostomy is also an option for managing mid-ureteral obstruction due to a retrocaval ureter. Matsuda *et al*. performed this procedure using interrupted 4-0 polyglactin sutures over a stent after resecting a 3-cm fibrotic retrocaval ureteral segment [43]. Furthermore, Polascik and Chen have reported a case of laparoscopic ureteroureterostomy for retrocaval ureter using the EndoStitch (US Surgical, Norwalk, CT, USA) suturing device [44]. Operative times were 7.5 and 3.7 h, and hospital stays were 1 and 2 days in these two cases, respectively.

Laparoscopic management of ureteral injuries employing a primary ureteroureterostomy has also been described, albeit in only a few cases. When a ureteral injury occurs during a laparoscopic procedure, for example, it can be primarily repaired over a stent using intracorporeal laparoscopic suturing without the need for open conversion. Tulikangas *et al*. described four cases of distal ureteral injuries during gynecologic procedures [45]. Laparoscopic ureteroureterostomy with intracorporeal interrupted sutures was performed over a ureteral stent. At a mean follow-up of 13 months (range 6–33), all four renal units showed no evidence of obstruction and no patient required repeat surgery. The overall clinical experience in laparoscopic ureteroureterostomy is broadening [46].

Ureterocalicostomy is a standard intervention for more proximal ureteral strictures that cannot be repaired with a primary ureteral reconstruction. As with ureteroureterostomy, laparoscopic technique should mirror the open surgical procedure. Laparoscopic renal mobilization is helpful. Resecting a generous portion of lower pole parenchyma and exposing a suitable calyx for anastomosis is key. Viable proximal ureter is spatulated and anastomosis performed with interrupted absorbable suture, commonly over a ureteral stent. Postoperative management and follow-up is identical to that employed with pyeloplasty. Both ureteroureterostomy and ureterocalicostomy reflect excellent minimally invasive interventions for moderate length ureteral strictures or injuries.

Laparoscopic Boari flap

When the diseased ureteral segment is distal and deemed too long for primary repair or when ureteral mobility is too limited to perform a tension-free ureteroureterostomy or a Psoas hitch ureteroneocystostomy, a Boari flap repair is a useful alternative. A Boari flap can be constructed to bridge up to a 15-cm long ureteral defect. Evaluation of bladder function should be performed preoperatively in addition to the aforementioned evaluation of the ureteral stricture. If there is evidence of bladder outlet obstruction or neurogenic dysfunction, this should be evaluated and addressed preoperatively. Additionally, the bladder should be of sufficient capacity to allow for creation of a sufficiently long Boari flap; otherwise alternative options should be considered.

A laparoscopic Boari flap has been successfully employed to treat long distal ureteral defects and strictures. Kavoussi *et al*. reported three successful cases where Boari flaps were used in the transperitoneal the management of distal ureteral obstruction [47]. Following open surgical principles, the bladder is mobilized from its peritoneal attachments and the most superior contralateral bladder pedicle is divided, allowing greater mobility toward the ipsilateral ureter. The ipsilateral bladder pedicle, including the superior vesical vasculature, is preserved and the affected ureter is carefully mobilized, with care taken to preserve its blood supply. Once the viable proximal ureter is defined, a posterolateral bladder flap is outlined based on the vascular supply of the ipsilateral superior vesical artery. The bladder flap is created and anastomosed to the spatulated ureteral end over a stent in a tension-free, watertight manner. Follow-up is based on serial evaluations, identical to the algorithm employed after open surgical repair.

In the report by Fugita *et al*., operative time ranged from 120 to 330 min, and blood loss ranged from 400 to 600 mL [47]. Two patients were discharged home within 3 days postoperatively, whereas one patient had a lengthy hospital stay due to *Clostridium difficile* colitis. Patency of the anastomosis was radiographically demonstrated at 6-month follow-up.

Conclusions

With advances in technique and endoscopic instrumentation, urologists are commonly employing minimally invasive therapies to address various urologic disorders, including ureteral obstruction. As progress continues in the field of endourology and laparoscopy, additional urologic procedures will be performed using a minimally invasive approach, reducing patient morbidity, while maintaining or expanding treatment efficacy. In this era of the endoscopist, minimally invasive treatment of ureteral strictures has not only become standard at teaching centers, but is also commonly employed in community settings worldwide.

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CHAPTER 44

Distal Ureteral Strictures

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Introduction

Disorders of the distal ureter are common encounters for most urologists. Strictures are the second most commonly treated disorder, superseded only by obstructing ureteral calculi. Distal ureteral strictures can be defined as an abnormal narrowing involving the lower third of the ureter. Luminal obstruction can be partial or complete, with varying resultant effect. Most strictures pose clinical significance when they impair the ureter's principal function of expeditious forward transport of urine. Such an effect can result in pain, infection, calculus formation, or renal dysfunction. It is the latter sequela that mostly critically beckon the need for accurate and reliable diagnosis, and effective and durable treatment.

Strictures have historically been managed with open repair. However, advances in ureteroscope design, technique, and experience have reduced the morbidity and mortality associated with endoscopic repair. The apparent increase in incidence of clinically significant distal ureteral strictures paralleling the increased diversity in treatment options may not be a coincidence. This can be partly explained by the iatrogenic nature of a large proportion of strictures diagnosed today. Endoscopic management of upper tract calculi and other disorders has evidently come at a cost.

This chapter reviews the causes, diagnosis, and endoscopic management of distal ureteral strictures.

History

Endoscopic repair of ureteral strictures draws its origins from the late 19th century and early 20th century with reports of mechanical ureteral stricture dilation by Palwick in 1891 and balloon dilation in the management of ureteral stones by Dourmashkin in 1926 [1, 2]. Over the next five decades, instrument development allowed for smaller caliber endoscopes with the incorporation of dilating and cauterizing instruments. Interest in the endoscopic treatment of ureteral strictures re-emerged, first with balloon dilation in the early 1980s [3, 4] followed by cold-knife incision [5] and electrocautery [6], as well as laser in 1997 [7].

Etiology

The choice of treatment option often depends on the cause of a stricture, making it worthwhile to be familiar with the mechanism of each cause. Distal ureteral strictures can result from intrinsic or extrinsic causes, benign or malignant (Table 44.1). A variety of intrinsic and extrinsic factors often elicit an inflammatory cascade, resulting in disordered deposition of collagen bundles and smooth muscle.

Iatrogenic ureteral injuries account for a large number of the benign causes and are more likely to occur during gynecologic surgery, accounting for 52–82% of all operative injuries to the ureter [8]. Risk factors for ureteral injury during gynecologic surgery include uterine size, pelvic organ prolapse, and prior pelvic surgery. The ureter is most likely to be injured at the crossing of the uterine artery [9, 10]. Urologic procedures contribute a fair share of iatrogenic ureteral injuries that can lead to subsequent strictures. The incidence of iatrogenic injury during ureteroscopy at one point was as high as 10%,

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Table 44.1 Etiology of distal ureteral strictures.

Intrinsic

Benign

- Iatrogenic structure:
  - Hysterectomy
  - Ureteroscopy
  - Transurethral resection of the prostate
  - Extracorporeal shock-wave lithotripsy
  - Percutaneous nephrolithotomy
- Inflammatory disorders:
  - Amyloidosis
  - Sarcoidosis
  - Inflammatory bowel disease
  - Henoch-Schönlein purpura
- Radiation fibrosis
- Congenital abnormalities
- Ischemia
- Impacted stones

Malignant

- Transitional cell carcinoma of the ureter
- Metastasis

Extrinsic

Benign

- Periureteral fibrosis:
  - Abdominal aortic aneurysm
- Endometriosis
- Infectious etiology:
  - Tuberculosis
  - Schistosomiasis
- Retroperitoneal fibrosis

Malignant

- Cervical cancer
- Prostate cancer
- Uterine cancer
- Ovarian cancer
- Colon cancer

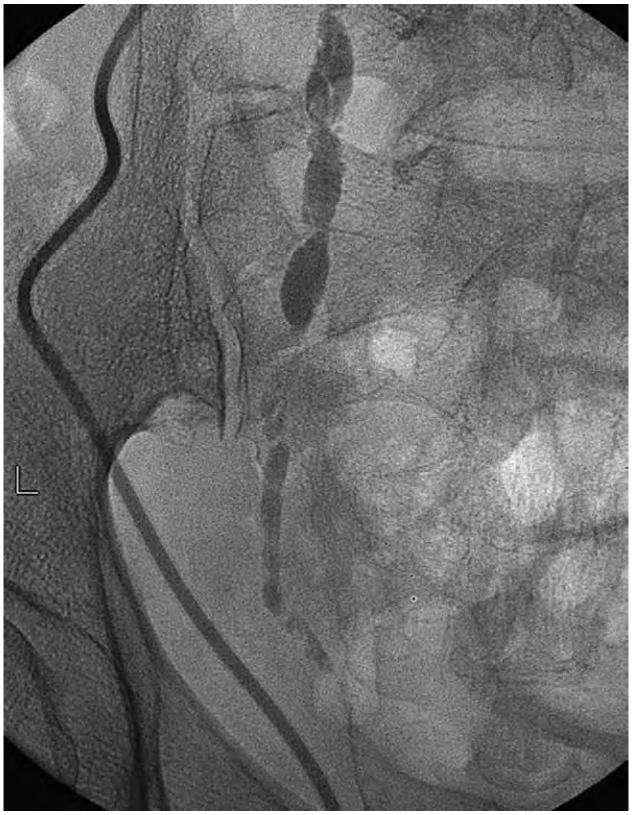

Figure 44.1 Distal ureteral stricture from tuberculosis.

but refinement in instrumentation and adoption of ureteral orifice dilation has reduced the stricture rate to less than 1% [11, 12]. Spontaneous passage of large stones or the passage of fragmented stones following extracorporeal shock-wave lithotripsy (ESWL) and percutaneous lithotomy (PCNL) procedures have also been linked to stricture formation [13–15]. In a retrospective review of 21 patients with a mean duration of stone impaction of 8.8 months, Roberts *et al*. found a statistically significant increase in stricture formation rates after 2 months of impaction [16]. Strictures can also result from bladder tumor resection in or around the ureteral orifice.

Benign conditions of the distal ureter that can result in strictures include ischemic, infectious, inflammatory, and congenital conditions. Ischemic conditions predispose the ureter to stricture formation, which is a recognized late complication in up to 10% of transplant nephrectomy [17, 18] and extrinsic compression by abdominal aortic aneurysms [19]. Infectious etiologies include tuberculosis [20] (Figure 44.1) and schistosomiasis [21], both of which have a constantly shifting demographic and geographic distribution. A number of inflammatory conditions can cause distal ureteral strictures, including endometriosis [22], sarcoidosis [23], amyloidosis [24], Henoch–Schönlein purpura [25], inflammatory bowel disease [26], and retroperitoneal fibrosis [27].

Malignant causes of distal strictures can mimic benign causes and must be ruled out when managing distal strictures. Causes of malignant obstruction can be of primary or metastatic origin and include transitional cell carcinoma of the ureter and metastases from the colon, cervix, prostate, bladder, or uterus. An important consideration in treating pelvic malignancies is the potential for stricture formation following pelvic irradiation.

Diagnosis

A detailed clinical history often reveals clues to the etiology of distal ureteral strictures. Symptoms of distal ureteral obstruction may include nausea, vomiting, flank pain, hematuria, and symptoms of upper or lower tract urinary tract infection. Worsening symptoms during diuresis or polyuria should raise the suspicion of the astute clinician. Depending on baseline renal function, signs of renal insufficiency can also herald the diagnosis of distal ureteral stricture-related obstruction. However, distal strictures are asymptomatic in 25% of patients with diagnosis made upon incidental imaging or during attempted ureteroscopy [28]. When evaluating suspected strictures, basic laboratory investigation should include a urine analysis, urine culture, serum creatinine, and coagulation studies to determine the prothrombin time, partial thromboplastin time, and platelet count.

The first imaging test that will often lead the clinician towards a diagnosis is renal ultrasonography to detect hydroureteronephrosis. Ultrasonography is noninvasive and radiation free, making it an appropriate highly sensitive screening test. The modality is rarely able to identify the location, extent or cause of a stricture, though, and thus usually requires an additional study to establish a diagnosis. Excretory urography or multidetector computed tomography (MDCT) urography can better characterize a distal ureteral stricture. CT urography, particularly with three-dimensional and coronal reconstruction, provides detailed anatomic depictions of the distal ureter and adjacent extraluminal structures by collimating submillimeter-thick scan slices. Limitations of CT urography include its potentially harmful ionizing radiation and the risks of intravenous contrast administration [29].

Multidetector magnetic resonance (MR) urography is a reasonable alternative to CT urography, as it provides similar cross-sectional imaging without the harmful ionizing radiation. Moreover, a reduced dose of gadolinium-based contrast can be considered for patients with renal insufficiency. MR urography is not without its limitations, including its inferior spatial resolution compared to CT urography [30]. MR imaging also is not possible in patients with some metallic implants.

When possible, retrograde ureteropyelography has the advantage of potentially being performed concurrently with planned treatment (Figure 44.2). In addition, it allows avoidance of intravenous contrast and boasts low levels of radiation exposure. However, it provides little information on extraluminal disease processes, and is not always possible if the obstruction is severe or involves the ureteral orifice. When retrograde imaging is not possible, antegrade imaging via percutaneous renal access provides excellent anatomic delineation of a distal ureteral stricture without intravenous contrast (Figure 44.3). The same access can be also used to perform a pressure-flow study (the Whitaker test) to quantify the degree of ureteral obstruction. Antegrade imaging is the most invasive option, however, and carries risks of bleeding and adjacent organ injury.

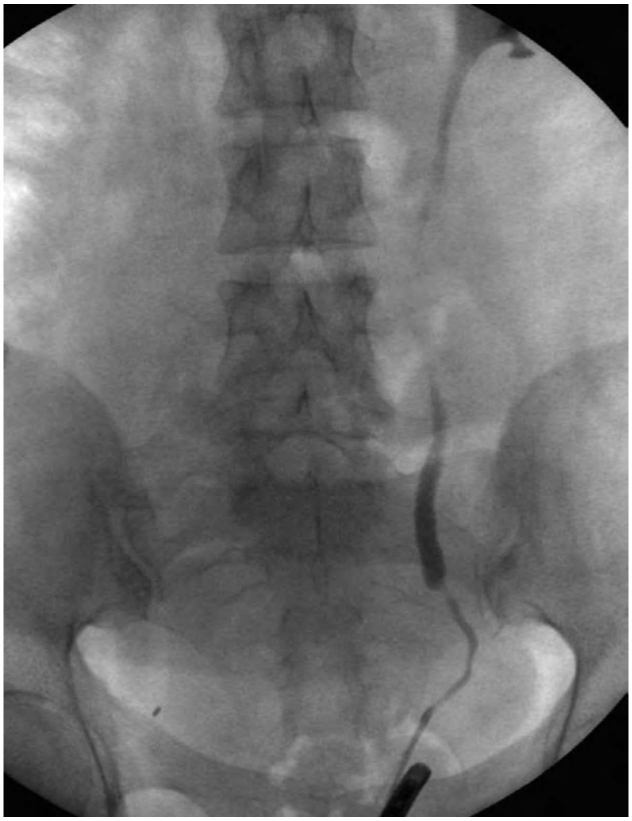

Figure 44.2 Retrograde ureterography demonstrating a distal ureteral stricture.

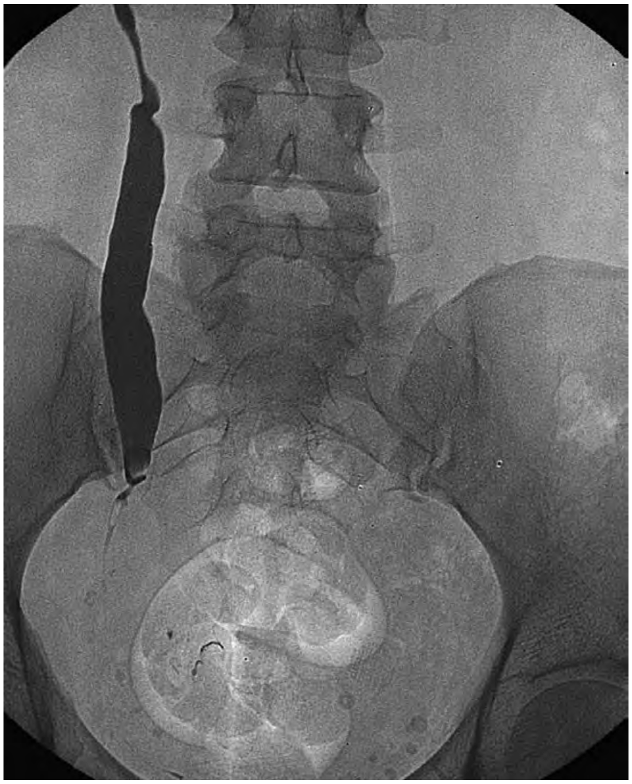

Figure 44.3 Antegrade ureterography demonstrating complete distal ureteral obstruction.

To quantify obstruction in a noninvasive manner, renal scintigraphy with diuretic washout provides the most accurate assessment [31]. Renal scintigraphy also allows the assessment of differential renal function, which may help guide treatment options. A renal unit contributing less than 15% of total renal function is associated with poor outcomes. If renal function is less than 25% on the ipsilateral side, observation alone is a reasonable option [32]. Temporary drainage with a percutaneous nephrostomy may be entertained and equivocal function reassessed after 4–6 weeks with renal scintigraphy, prior to definitive therapy.

Endoluminal ultrasonography has been a promising technique in assessing ureteral strictures. While it has fallen out of favor somewhat, endoluminal ultrasonography can provide useful anatomic detail of a stricture, including stricture length, the presence of extraluminal vascularity, and the extent of periureteral scarring and fibrosis. With experience, this modality can identify potential causes or associated conditions, such as ureteral endometriosis, retroperitoneal fibrosis, and surgical clips and staples [33]. Ultrasonography requires the ureteral caliber to allow the passage of a 6F probe and requires transurethral introduction via cystoscopy. A smaller 3.5F probe is available and may be passed through the working channel of some ureteroscopes. It is, therefore, only useful in partially obstructing distal ureteral strictures.

Preoperative preparation

Prior to intervention, all urinary tract infections should be treated and confirmation of treatment established with documentation of sterile urine preoperatively. Prophylactic preoperative antibiotics are indicated in all patients and can be given as single-dose therapy or continued for one to two doses after the procedure [34, 35]. Any suspicion of coagulopathy should prompt evaluation with appropriate testing and should be corrected preoperatively.

The patient is typically positioned in a dorsal lithotomy position for retrograde ureteroscopic approaches. If concurrent antegrade access is probable, the patient is placed in a prone split-leg position [36]. However, as comfort with supine percutaneous renal access increases, combined antegrade and retrograde approaches may be performed in a dorsal lithotomy position with the ipsilateral flank raised. Retrograde or antegrade ureterography under fluoroscopy is performed concurrently with treatment to map treatment. Access is achieved under fluoroscopy by passage of the surgeon's guidewire of choice. Initial access with an angled hydrophilic floppy-tipped guidewire may be needed to traverse some strictures.

Treatment options

Temporary relief of obstruction resulting from ureteral strictures is often achieved using ureteral stents or percutaneous nephrostomy. Patients with refractory strictures or who are not candidates for definitive treatment will often submit to long-term stent or nephrostomy exchange as a permanent solution. Stents for distal strictures resulting from extrinsic obstruction often are an unsuccessful long-term solution, with percutaneous drainage usually necessary after delayed stent failure [37]. Definitive treatment options for distal ureteral strictures include balloon dilation and ureteroscopic endoureterotomy.

Balloon dilation

Retrograde balloon dilation is often the first treatment attempted for distal ureteral strictures (Figure 44.4). Ureteral balloons vary in length (4–10 cm) and inflated diameter (4–10 mm), and can withstand maximum pressures of 40–225 pounds per square inch (psi). Using a porcine model, Clayman *et al*. demonstrated that the distal ureter can be safely dilated up to a caliber of 24F [38]. While perspectives differ on the optimal balloon size and technique, we prefer a 4-cm long, 6 mm (18F)

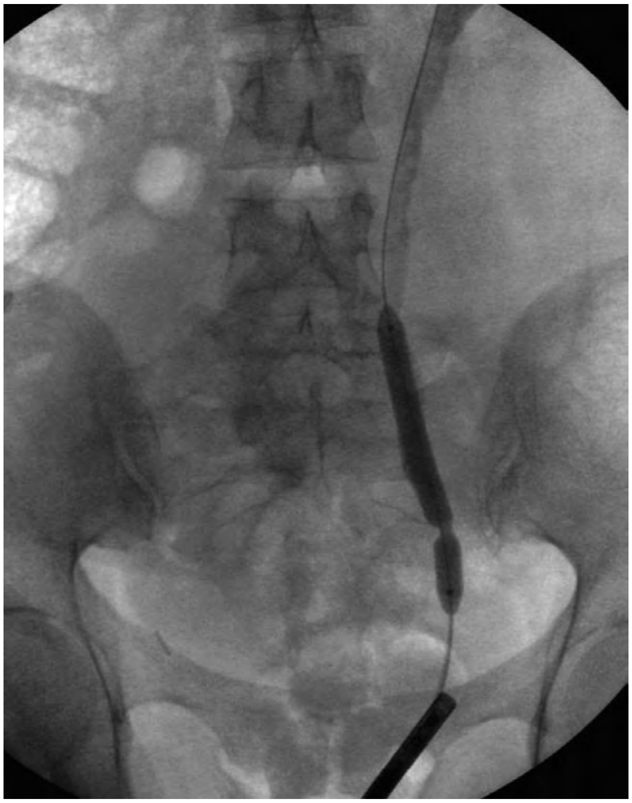

Figure 44.4 Balloon dilation of a distal ureteral stricture with "waisting."

balloon for most strictures. The success rate of retrograde balloon dilation for ureteral strictures has been estimated to be 48–88%, with a 10–29-month follow-up [1]. Predictors of durable success for balloon dilation include nonischemic strictures that are less than 1.5 cm in length and strictures that are less than 3 months old [39, 40]. In contrast, patients with ischemic strictures of longer lengths have demonstrable poor outcomes after balloon dilation with a patency rate of 16.7%.

Retrograde balloon endoureterotomy

The Acucise™ device (Applied Medical, Rancho Santa Margerita, CA, USA) incorporates a low-pressure ureteral balloon dilator with monopolar electrocautery for retrograde incisions under fluoroscopic guidance [41]. The balloon helps identify the diseased segment (as demonstrated by "waisting") and provides tamponade following cauterized incision. With only fluoroscopic guidance possible, careful patient and stricture selection is needed to help reduce hemorrhage risk. Additionally, the cutting wire should be oriented in an anteromedial position when incising the ureter distal to the iliac arteries, and should never be used at the level of iliac vessel crossing. For an incision to be effective, cutting should be extended through the full thickness of the ureteral wall until periureteral fat is visible or until an adequate luminal diameter has been established. Without direct visualization, this translates into contrast extrusion on a subsequent retrograde ureterogram. Incision also should extend at least 2 mm proximal and distal to the area of stricture, and not just until balloon waisting is lost.

Preminger *et al*. evaluated the efficacy of the Acucise device in 26 patients with distal strictures, and found 58% were patent and a further 15% improved after an average follow-up of 7.8 months [41]. Knowles *et al*. performed balloon endoureterotomy using the Acucise device for 10 strictures in nine patients with complete distal ureteral obstruction [42]. They used a mixture of approaches (retrograde, antegrade, and combined), and found 90% success with a durable median follow-up of 36 months. The use of endoluminal ultrasonography prior to balloon endoureterotomy using the Acucise device reduced associated complications in a study by Hendrikx *et al*. [43]. The group found no bleeding in a series of 27 patients following endoluminal ultrasonographic markings of periureteric structures.

Ureteroscopic endoureterotomy

A limitation of balloon endoureterotomy for ureteral strictures or ureteropelvic junction obstruction is the lack of direct visualization. Incision of strictures via ureteroscopy can be achieved using different modalities, including a cold knife, electrocautery, or holmium:YAG laser. Cold-knife incisions can be performed with straight, hook, or half-moon configured blades under direct vision via a rigid ureteroscope. Incisions are made under endoscopic visualization and always with guidewire access control (when not precluded by complete obstruction) [44]. Using a cold-knife incision has the advantage of a relatively low local inflammatory and cicatricial response because of the lack of energy transmitted [45]. Cold-knife endoureterotomy has overall high rates of success for primary and salvage procedures. The largest series to date of distal endoureterotomies performed with a cold knife was reported by Eshghi and Lifson, showing a 95% success rate for 100 strictures in 89 patients [28].

Electrocautery can be used to incise distal ureteral strictures via ureteroscopy using 2–3F ball-tip electrocautery probes. While electrocautery boasts better hemostasis than a cold knife, it results in a more substantial local tissue response, which carries a high stricture recurrence risk. Electrocautery requires the access guidewire to be a well-insulated wire, or alternatively a narrow ureteral catheter, to prevent longitudinal transmission of the current. A few studies have evaluated the efficacy of electrocautery in the distal ureter, including one by Ghoneim *et al*. demonstrating success in only two of 10 patients with distal ureteral strictures, with failures attributed to bilharzial and iatrogenic strictures [46].

Combining accuracy and reduced local response, laser endoureterotomy is associated with the most favorable results for distal ureteral strictures. Holmium:YAG lasers can be operated at 10 W (10 J at 10 Hz) with low-power generators and through 200-μm laser fibers that can pass through either semi-rigid or flexible ureteroscopes [1, 47]. Holmium:YAG lasers have the versatility of treating any associated calculi. Thirteen patients with stricture disease secondary to stone disease underwent laser endoureterotomy with a success rate of 56% [48]. In a large review of patients undergoing laser endoureterotomy with holmium:YAG, Lane *et al*. reported a success rate of 75% with a mean follow-up of 36 months, and found that failures were most likely within 3 months of treatment [49]. Despite the precision of laser endoureterotomy, Figenshau *et al*. found no significant difference in the histologic changes between balloon dilation, Acucise, and endoscopic incision with a cold knife, laser, or electrocautery in a porcine model [50]. Similarly, Wolf *et al.* found no difference between the cutting modalities in a multivariate analysis with an overall success of 80% at 3 years [32].

Ureteral stenting after treatment of distal strictures is generally not contested. Stent use theoretically prevents recurrent stricture formation and urine extravasation, and promotes healing [1]. The choice of stent type and size has been the subject of much debate, without definitive data to support the superiority of one. We prefer the use of a 7F double pigtail stent, although two 6F stents or a gently tapered endoureterotomy stent (6/10F) are viable alternatives. We recommend stent use for 6 weeks after treatment of a stricture. Stricture recurrence should be ruled out between 6 and 12 weeks after stent removal with renal ultrasonography, CT urography, excretory urography, or diuretic renography. Asymptomatic patients with normal early postoperative imaging should be reimaged at 6-month intervals for up to 3 years, as strictures are most likely to recur within the first 3–36 months [32, 49, 51].

Challenging strictures

Ureteroenteric strictures

Ureteroenteric strictures are recognized late complications of 3–10% of urinary diversion procedures [52–54]. Ischemia is the most likely precipitating factor (Figure 44.5). Numerous endourologic techniques have been applied in the management of these complex strictures, including balloon dilation (Figure 44.6), balloon endoureterotomy, and ureteroscopic endoureterotomy. A combined antegrade and retrograde approach is often necessary due to the complexity of these strictures. In a review of 30 strictures in 25 patients by Wolf *et al.*, the overall success rate for all endourologic procedures in the treatment of ureteroenteric strictures was estimated to be 72%, 51%, and 32% at 1-, 2-, and 3-year follow-up, respectively [32]. They also found that right-sided endoureterotomies had significantly better outcomes compared to left-sided endoureterotomies (68% vs 17%). This difference could be attributed to ischemia due to the more convoluted course of the left ureter posterior to the sigmoid colonic mesentery, and the higher likelihood of tension on the ureteroenteric anastomosis. Cold-knife endoureterotomy has been reported to have a 3-year success rate of 60.5%, closely followed by holmium:YAG endoureterotomy with a 56% patency rate at 3 years [55, 56]. Ureteroenteric strictures are discussed further in Chapter 45.

Renal transplantation strictures

Ureteral strictures following renal transplantation are associated with patient and graft morbidity, and can result in graft loss or death. Stricture rates are related to the reimplantation technique used. The highest rates of ureteral stricture have been observed with the Leadbetter–Politano anastomosis (12.4%) [57–60]. The majority of post-transplant strictures present distally and often involve the ureterovesical junction [61, 62].

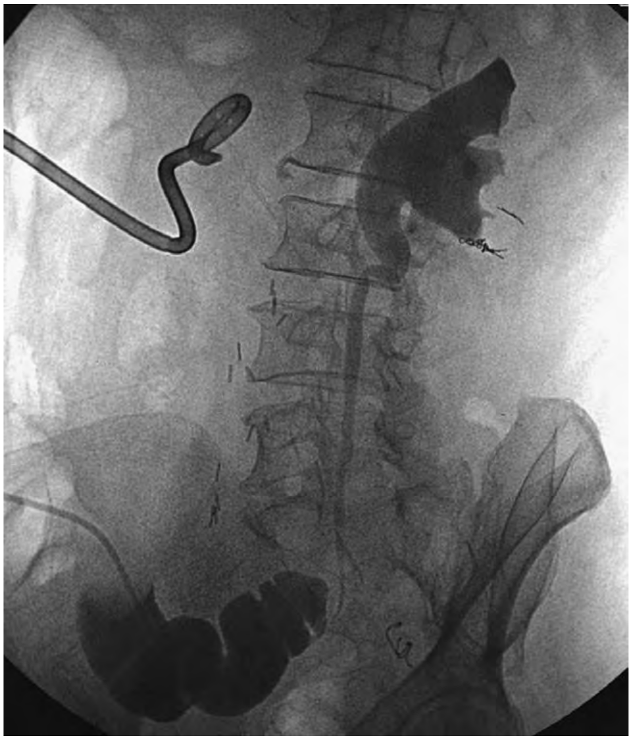

Figure 44.5 Ureteroenteric stricture.

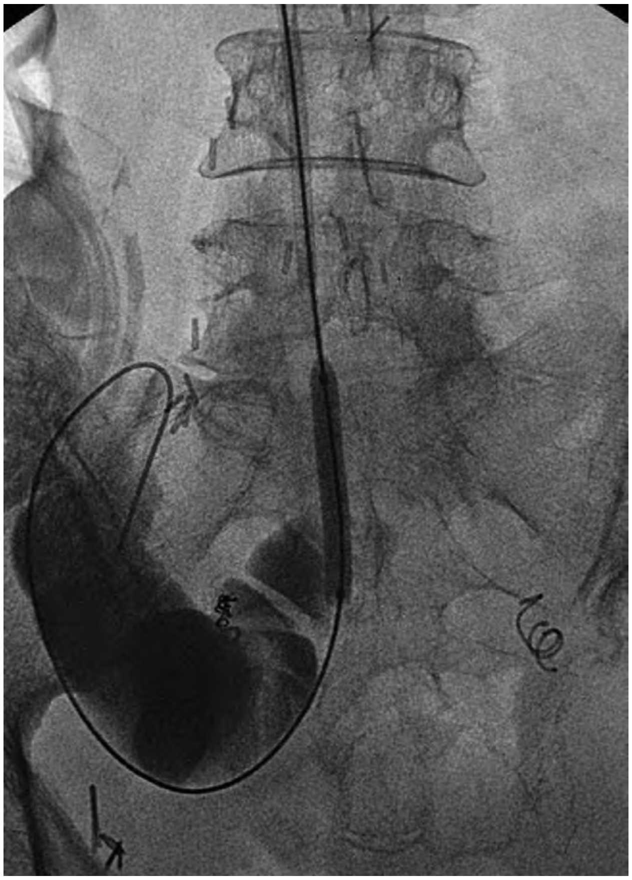

Figure 44.6 Balloon dilation of ureteroenteric stricture.

Retrograde or percutaneous ureteral balloon dilation is the initial method of choice in treating ureteral strictures and has been performed with varying success rates. Lojanapiwat *et al*. demonstrated a 71% success rate using antegrade balloon dilation for strictures that presented within 3 months of transplantation, in contrast to only 29% for strictures treated greater than 3 months after transplantation [62]. Bosma *et al*. treated 13 patients with a retrograde, antegrade, or combined approach, with dilation only in nine patients and dilation and electrocautery in four patients. After a mean follow-up of 58 months, four of the patients who underwent dilation alone developed recurrent obstruction [63].

Endoureterotomy techniques have also been used in the treatment of renal transplant strictures. Synergistic effects between antegrade balloon dilation and holmium:YAG endoureterotomy were seen in a study by Gdor *et al* [64]. The group showed success in four of six patients with a combined approach, compared with only one of three patients treated with balloon dilation alone. Conrad *et al*. evaluated cold-knife endoureterotomy for 11 transplant strictures and found 82% patency after 26 months of follow-up [65]. The Acucise device was successful in two of three patient with transplant strictures after a mean of 20 months [66].

Subtotal and total obstruction

Advances in technique and instrumentation have expanded the role of endoscopic approaches to include ureteral strictures causing complete or near complete obstruction. Bach *et al*. recently described their technique of blind retrograde endoureterotomy, which is performed under fluoroscopic control using either a holmium:YAG or thulium:YAG laser slowly pulled through the stenotic area [67]. However, 38.8% of patients developed recurrence of obstruction after a median follow-up of 1 year. To perform blind retrograde endoureterotomy, a glidewire and a 4F catheter must be passed through the stricture. Alternatively, passage of microwires and microcatheters can be attempted percutaneously in an antegrade fashion [68, 69].

For short complete obstructions less than 2 cm in length, endoscopic recanalization can be performed with a "cut-to-the-light" procedure [70]. This approach requires percutaneous access for a flexible ureteroscope to pass down the ureter. A semi-rigid ureteroscope is simultaneously passed up the distal ureter. The light transmitted from one endoscope guides the electrode or laser of the other endoscope. Recanalization was successful in a case series of three patients using the holmium:YAG laser [71]. Alternatively, the stiff end of a guidewire can be used to pierce the obstructing tissue with subsequent dilation. Using this technique, Colins *et al*. demonstrated a 100% recanalization rate and 75% long-term success in eight patients after a median follow-up of 87 months [72]. Similar results were obtained by Tsai *et al*., who combined ureteroscopy with a fluoroscopic-guided antegrade snare to re-establish ureteral continuity in 10 patients with a mean follow-up of 16 months [73].

Conclusions

Distal ureteral strictures are encountered by every urologist. The etiology, severity and extent, associated renal function, and adjacent pathology should dictate the approach for management. A tailored systematic algorithm should be planned for each patient, being mindful of success rates and complications. When endourologic management fails to achieve durable results, open and laparoscopic approaches should be considered.

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CHAPTER 45

Endoscopic Management of Ureteroenteric Strictures

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Introduction

Ureteroenteric strictures following radical cystectomy and urinary diversion have a reported incidence of 4–8% [1, 2]. Following the diagnosis, management of these strictures represents a treatment dilemma. While open exploratory laparotomy and revision of the narrowed anastomosis is the gold standard treatment, with success rates of 89–91% [3, 4], surgical revision can be technically challenging secondary to dense fibrosis and adhesions associated with the prior surgery or radiotherapy. Advances in endourologic instruments and techniques have allowed many endoscopic procedures to be used in the primary management of ureteroenteric strictures. While long-term success rates have not been as robust as those for open treatment, these less invasive techniques uniformly offer shorter hospitalization, reduced blood loss, and quicker convalescence [5]. This decreased associated morbidity may be particularly beneficial in patients who would otherwise be poor surgical candidates. As the overall incidence of ureteroenteric strictures is relatively low, most studies describing the various endoscopic procedures are limited to small case series or single institution experiences, making overall evaluation difficult. However, some concerns exist for patients who fail endoscopic treatments. Contemporary reports of open revision suggest slightly lower long-term success rates (76–80%) than previously noted [6, 7]. Some authors hypothesize that this may be secondary to inclusion of more difficult patients who previously failed primary endoscopic management [7].

In this chapter, we review the endoscopic management techniques of ureteroenteric strictures and detail the outcomes of the various approaches in the literature identified by a PubMed and MEDLINE search in order to determine which patients could undergo endoscopic intervention and which should be offered open revision as first-line therapy.

Etiology and characteristics

Ureteroenteric strictures are most commonly classified as benign and ischemic in origin, and have been reported following all types of urinary diversions [8]. Malignant recurrence at the anastomosis is rare, with reported rates of 0–0.7% [9–11]. The etiology of ureteroenteric strictures is largely multifactorial. Several technical considerations at the time of radical cystectomy may promote stricture development. Inadequate ureteral length or extensive skeletonization of the periureteral microvasculature during ureteral mobilization and diversion creation may result in compromised blood supply to the distal ureter. The longer ureteral course to meet the bowel as well as misapproximation of the ureteroenteric anastomosis may promote ureteral angulation or torsion [12]. This likely reflects the predominance of left-sided strictures often observed secondary to the length and degree of mobilization required to tunnel the left ureter under the mesentery [13]. Additionally, inherent differences with the apposition of the two different mucosal types, as well as urinary exposure and autoimmune responses, may promote stricture formation [14, 15]. The

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type of ureteroenteric anastomosis after urinary diversion may also relate to stricture occurrence. Despite an increased risk for bilateral renal obstruction, the conjoined end-to-end ureteral anastomosis (Wallace) has a lower reported stricture rate as compared with the individually implanted ureteral anastomosis (Bricker) [16, 17], though this has not been uniformly observed [18]. A direct refluxing anastomosis generally has a decreased stricture incidence compared to antirefluxing anastomoses [19], though some variability has also been reported [20]. Other factors that have been implicated in the development of ureteroenteric strictures include the use and type of ureteral stent at the time of diversion [21, 22], patient obesity [body mass index (BMI) >30 kg/m^2], and pelvic radiation therapy [16].

Diagnosis

Patients with ureteroenteric strictures may be symptomatic on presentation with unexplained flank pain, hematuria, or recurrent urinary tract infections (UTIs) [23, 24]. However, in other patients, the diagnosis is made on evaluation of increased serum creatinine or incidentally noted with the finding of hydronephrosis on imaging, which reiterates the importance of regular, routine follow-up (Figure 45.1). Initial radiographic studies typically include computed tomography (CT) or renal ultrasonography to evaluate for hydronephrosis. Additional functional imaging such as renal scintigraphy, excretory urography, antegrade nephrostography, or loopography/neobladder cystography should be performed in order to confirm the diagnosis and determine the stricture length and location (Figure 45.2). Reflux from urinary diversion should be excluded from the diagnosis as chronic reflux can cause hydronephrosis without obstruction. Urine cytology should be examined in all patients to rule out malignant recurrence. As many of these patients have undergone diversion secondary to a history of primary bladder or pelvic malignancy, a high index of suspicion for malignant obstruction should be maintained and appropriate cross-sectional imaging and endoscopic visualization to rule out malignant obstruction should always be undertaken prior to definitive stricture treatment. In patients with suspicious lesions, ureteral biopsies may be required for definitive diagnosis.

Indications for intervention

Early decompression is generally warranted in patients with ureteroenteric strictures. In patients with significant flank pain or concerning infection, prompt drainage can relieve symptoms or prevent impending sepsis. Asymptomatic patients with ureteroenteric stricture are at risk for developing worsening hydronephrosis and compromised renal function. These two factors, specifically an ipsilateral renal function of less than 25%, have been associated with poor outcomes following ureteroenteric stricture treatment [13]. Percutaneous nephrostomy is the most common and effective method for early decompression. This also allows for antegrade

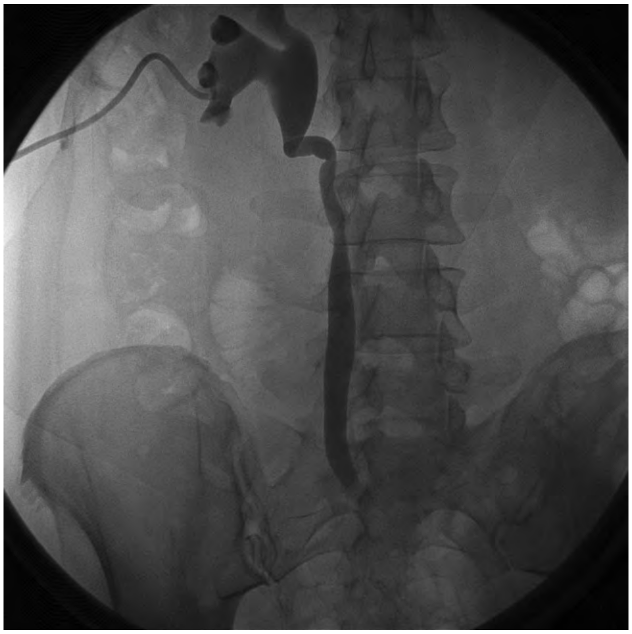

Figure 45.1 Antegrade nephrostogram. Left ureteroenteric stricture in patient with Bricker-type ileal conduit resulting in hydroureteronephrosis.

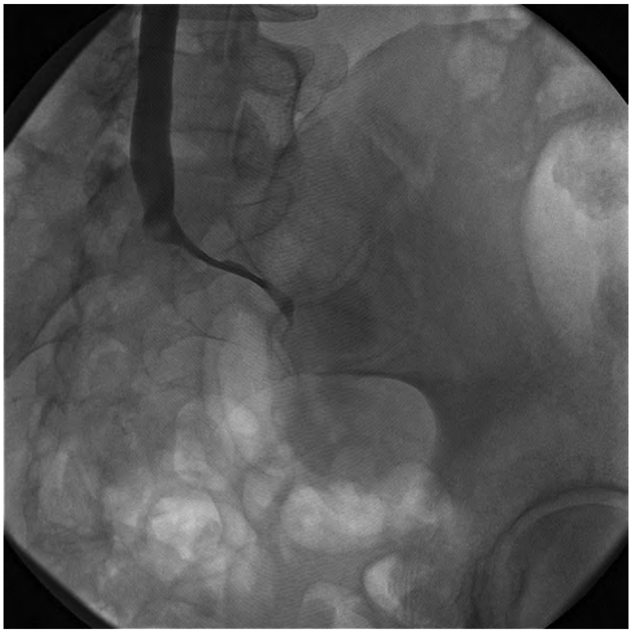

Figure 45.2 Antegrade ureterogram delineates ureteroenteric stricture.

diagnostic studies to be performed while awaiting renal function and infections to improve prior to definitive therapy.

Surgical techniques

Endoscopic management of ureteroenteric strictures can be performed using an antegrade, retrograde, or a combination of the two approaches. As we typically decompress patients with a percutaneous nephrostomy tube after the initial discovery of obstruction, we generally approach the stricture in an antegrade fashion. An angled-tip 0.038-inch hydrophilic nitinol core glidewire is advanced through the previously placed nephrostomy access and manipulated into the conduit or neobladder. A 5F Cobra-tipped angiographic catheter is used to help facilitate wire positioning into the ureter if necessary. The glidewire is next exchanged for an Amplatz super-stiff wire. A second standard guidewire is placed as a safety wire down the ureter following placement of an 8/10F coaxial dilator over the super-stiff wire. Depending on surgeon preference, a variety of types of tract dilatation and sheath placement are possible. For ureteral evaluation and treatment, we typically prefer placement of a smaller diameter 18F Amplatz sheath or a short 13 or 15F ureteral access sheath. Both flexible ureteroscopy and an antegrade nephrostogram are performed to characterize the location and degree of stenosis. Biopsies and washings for cytology should be taken to evaluate for recurrence in all cases of transitional cell carcinoma where suspicion is high for malignant obstruction. In patients with significant tortuosity and angulation of the ureter, an 11/13F x 36 cm ureteral access sheath is placed through the Amplatz sheath in order to negotiate to the distal ureter. Further individualized endoscopic management is detailed below.

Balloon dilation

Balloon dilation of the ureteroenteric stricture can be performed primarily or in conjunction with another endoscopic modality such as endoureterotomy. After manipulation of the guidewire past the area of stenosis, a UroMax Ultra Balloon catheter with an outer diameter of 15–18F at a length of 4 cm is placed in the narrowed region under fluoroscopic guidance. The balloon is inflated to approximately 12–15 atm until the narrowed waist is removed (Figure 45.3). After maintaining the dilation for 3–5 min, the balloon is deflated and removed. Flexible ureteroscopy is performed in order to inspect the strictured site. Repeated balloon dilation can be performed for any residual scar tissue. At the conclusion of the procedure, a stent is placed across the dilated segment (see Stenting options below).

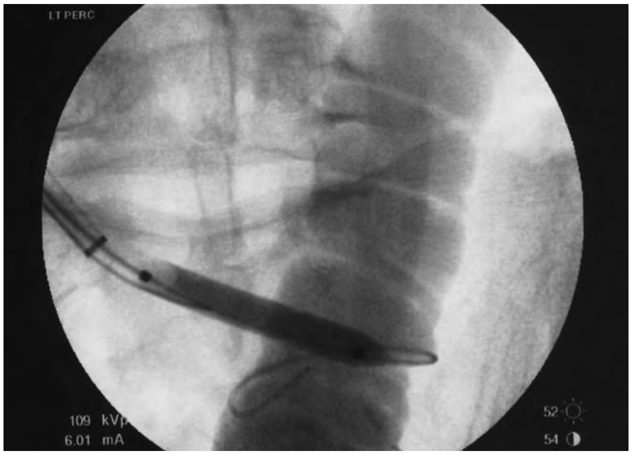

Figure 45.3 Balloon dilation of distal left ureteroenteric stricture after cystectomy.

Endoureterotomy

Incision of the strictured ureteral segment can be performed using a variety of cutting sources [cold, hot (electrosurgical probes/Acucise™), holmium:YAG laser] either under direct vision or fluoroscopic guidance. In significantly narrowed ureters, initial balloon dilation may be required to allow complete access to the stricture. A full-thickness incision extending 1 cm beyond both ends of the strictured area is made through the ureter until periureteral fat is noted or contrast extravasation is observed under fluoroscopy [25]. Some investigators have advocated the adjunct use of triamcinolone steroid (3–5 mL at 40 mg/mL) injected endoscopically with a 3F Greenwald needle into the incised stricture bed for improved patency [13, 26]. After direct visual or fluoroscopic confirmation of the desired stricture release, a stent is placed. Detailed descriptions regarding each type of cutting device are listed below.

Cold knife

Cold-knife endoureterotomes are generally used with semi-rigid ureteroresectoscopes for retrograde incision of the stricture. The larger diameter sheath and lack of flexibility of the scope limits the extent of narrowing that can be treated under direct visualization. The stricture is cut using arc-like strokes until the ureteral lumen widens enough to allow passage of the scope. Small mucosal bleeding vessels are not routinely fulgurated to minimize the extent of potential thermal injury [27]. A flexible, wire-mounted cold-knife has been described that allows both antegrade and retrograde incision. The wire can be placed through the working channel of the scope to directly guide the blade through the shaft of the knife or pulled under fluoroscopic guidance. Several incisions may be required to fully release the fibrotic stricture [28].

Electrocautery

Under direct visualization, the smaller Greenwald 2 or 3F electrode probe can be utilized through the semirigid or flexible ureteroscope. At a power setting of 75 W on pure cutting electrocautery current, multiple incisions of the stricture are made using the probe until the fibrotic bands are released. The incision width and length can be fully controlled under direct visualization and hemostasis can be achieved if necessary. A variation of the technique has been described by Lovaco *et al*. that incorporates a dilation balloon pulled in a retrograde fashion to invaginate the stricture and allows subsequent intraluminal incision of the complete, well-exposed stricture using electrocautery [24]. Care must be taken to insulate any safety wires that might be exposed to electrical current to prevent conduction to other segments of the ureter or tract.

Acucise™ balloon catheter

The 7F Acucise cutting balloon catheter combines a monopolar electrocautery cutting wire and a 24F low-pressure balloon, and can be placed either in an anterograde or retrograde fashion. Though originally developed for treatment of ureteropelvic junction obstruction (UPJO), the device is approved by the Food and Drug Administration (FDA) for use throughout the ureter [29]. After direct visualization of the narrowed area, the Acucise catheter is advanced over the guidewire using fluoroscopic guidance with the radio-opaque markers at either end of the 3-cm active cutting surface positioned in the area of the ureteroenteric stricture. Attention is given to position the cutting wire in the posteromedial orientation after visual confirmation of an absence of any pulsations in the area of the proposed cut. The Acucise balloon is subsequently inflated with 2 mL of contrast along with simultaneous activation of the cutting wire at 75 W on pure cutting electrocautery current for 5 s. After maintaining the dilation for 3–5 min, the balloon is deflated. It can be repositioned to traverse any residual narrowing and reactivated as needed.

Laser

Ureteroenteric stricture incision is performed at the 6 o'clock position with the patient in the prone position, away from the iliac vessels. A 200-μn holmium:YAG laser fiber is placed through the flexible ureteroscope at a setting of 10 W (1 J and 10 Hz) and used to incise the fibrotic tissue under direct visualization until release of the scar tissue and periureteral fat is evident [30]. Contrast instillation through the endoureterotomy site may show a small amount of extravasation, confirming the adequacy of the incision. While other types of lasers (Nd:YAG, KTP Nd:YAG) can be used for stricture incision, the holmium:YAG is predominantly used because of its ablative and hemostatic properties [25]. With a depth of penetration of less than 0.5 mm, the laser allows for precise incision with a minimal peripheral zone of thermal injury (0.5–1 mm) [5].

Ureteral stenting

Most patients treated with balloon dilation or endoureterotomy additionally undergo ureteral stent placement at the conclusion of the procedure. The stent remains for a finite period of time in order to maintain ureteral patency, prevent urine extravasation, and promote healing. The optimal stent duration is unclear. Significantly prolonged stent duration, however, may promote hyperplastic tissue growth or scarring and prevent adequate healing [25]. Additionally, there is a lack of consensus regarding optimal stent size. Some authors advocate larger stents [13], though others believe that increased pressure from oversized stents may promote fibrosis and recurrent strictures [31]. The stent can be positioned either antegrade or retrograde after establishing guidewire access across the ureteroenteric stricture in a through-and-through fashion. Double-J stents are most commonly used but may be difficult to exchange in patients with incontinent diversions. In patients with an ileal conduit, a nephroureteral stent can be advanced over the exposed guidewire from the stoma in a retrograde fashion to the renal pelvis, with the external portion of the stent placed in the stoma bag for external drainage [32]. In patients who are too ill for more definitive therapy or it is their preference, chronic indwelling ureteral stents may be utilized as the primary treatment. All synthetic stents, however, require periodic exchange secondary to subsequent encrustation and obstruction. Double-J stent exchange is generally recommended every 3–6 months and typically requires an anesthetic in the operating room.

The use of metal ureteral stents for ureteroenteric strictures is controversial. Metallic stents have proven success in other organ systems but, in urology, have primarily been employed for malignant ureteral obstruction [33]. Full-length, double-pigtail metallic stents similar to synthetic double-J stents have the advantage of once-yearly exchanges. Initially, a metallic stent introducer is passed over the existing guidewire. After removal of the wire, the metallic stent is passed through the lumen of the introducer sheath. The sheath is subsequently removed, leaving the stent in place [34]. Short, permanent, balloon, or self-expandable metal stents, similar to vascular stents, have also been utilized for ureteroenteric strictures. They do not require exchange. These metallic stents are deployed using a manufacturer delivery system over the guidewire and positioned such that 3–4 cm of the stent extends beyond the stricture proximally and 0.5–1 cm distally. Attention is given to ensure that less than 0.5 cm of the stent protrudes distally into the neobladder or ileal conduit lumen to minimize urinary contact. After fluoroscopic confirmation of proper positioning, the outer sheath of the delivery system is removed, thus releasing the stent. If necessary, two or more stents may be placed in tandem for longer strictures [33].

Retrograde approaches

While antegrade or combined antegrade/retrograde approaches are generally utilized in the management of ureteroenteric strictures, direct retrograde access can conversely be attempted to minimize the potential morbidity of percutaneous techniques. Initial retrograde access can be challenging secondary to inability to locate the ureteral orifice within the intestinal mucosal folds of the diversion or difficult location or angle of the ureteral orifice. Additionally, access to the orifice may be prohibited in patients with very long or tortuous diversion limbs. Identification of the ureteral orifice may be aided by the excretion of indigo carmine following intravenous administration [35]. Also, contrast instillation within the urinary diversion may allow for better delineation of the appropriate diversion limb and location of the ureteral anastomosis [36]. Retrograde access is generally not feasible in patients with nonrefluxing anastomoses secondary to the antireflux mechanism [37]. However, in other patients, once the ureteral orifice has been identified, a straight or angled-tip 0.038-inch hydrophilic nitinol core glidewire in combination with a 5F Cobra-tipped angiographic catheter can be used to help facilitate access into the ureter. Wire advancement through the obstructed segment may be difficult in patients with significant stenosis or long (>1 cm) strictures and require antegrade approaches. Following wire placement past the level of obstruction, any of the previously discussed endoscopic techniques may be utilized.

Surgical outcomes

While there is some variability in the literature, operative success was defined as radiographic improvement/resolution of obstruction and/or a recovery to normal activity without flank pain, infection or need for ureteral stent/nephrostomy tube [24, 28, 38].

Balloon dilation

In eleven publications describing 150 primary balloon dilations of ureteroenteric strictures in both continent and incontinent diversions, success was reported in 0–67% (mean 33%) of cases at a mean follow-up of 4–48 months (Table 45.1) [6, 12, 23, 39–46]. While initial results appeared favorable, later results have been less promising at longer follow-up. Review of the largest and more contemporary series shows patency rates of only 15% at a 1- and 2-year follow-up, which decreased to 5% at 3 years [6].There was no consensus regarding balloon size (4–10 mm), inflation time (30 s—10 min), number of inflation cycles (1–3), or inflation pressures (5–17 atm). Additionally, while most studies utilized stents at the conclusion of the procedure, a variety of stent sizes (5–24F) and duration of stenting (days to months) was reported. Although there were no uniform predictors of success and not every publication evaluated each parameter, some trends were observed. The side of the stricture and degree of stenosis did not influence outcomes. Longer strictures (>1–2 cm) were less likely to have long-term success. A shorter duration between urinary diversion and balloon dilation was a more likely predictor of success, though this was not uniform [6, 12, 23, 39–46].

The poor durable results of this technique may be explained by the physiologic effects of balloon dilation. Single-step, high-pressure balloons allow radial dilation of the stricture without the shearing trauma associated with serial stepwise catheter dilation [29]. However, as noted for UPJO, poor long-term results following balloon dilation of ureteroenteric strictures may occur because the epithelium and lamina propria are split without a corresponding split to the muscularis propria or adventitial layer [47, 48]. Additionally, hydraulic trauma to the neighboring healthy ureter may result in further ischemic damage [30].

Endoureterotomy

Incision of the strictured ureteral segment, whether by cold knife, electrocautery, electroincision or laser, is the current endoscopic standard [23]. The technique is based on animal studies by Davis in 1943 with intubated ureterotomy [49]. Davis noted that incised ureters healed over a stent by regrowth of the urothelium and subsequent smooth muscle within approximately 6 weeks. Ureteral patency was noted in 70% of incisions [50]. Later animal studies involving endoureterotomy noted that there were no significant difference in tissue injury, periureteral edema, and inflammation regardless of the cutting modality used [48].

In 17 studies involving 147 endoureterotomy procedures, overall success was reported in 30–100% (mean 66%) of cases at a mean follow-up of 10–60 months (Table 45.2) [3, 5, 13, 23, 24, 26, 28, 30, 38, 51–58].While the total numbers of procedures in each group were comparable, small procedure numbers in each individual case series make direct comparison between the

Table 45.1 Outcomes of balloon dilation repair of ureteroenteric strictures and predictors of success.

Study	Number of procedures	Mean follow-up (months)	Success rate (%)	Diversion type	Time to conduit creation vs procedure	Stricture location (left, right)	Stricture length	Stricture diameter	Balloon size (mm)	Duration/ cycles/ pressure	Stent size (French)	Stent duration (weeks)
Milhoua *et al.* 2009 [23]	4	16	0	Ileal conduit, neobladder	NS	NS	NS	NS	DS	DS	6–16	1.5–9
Tal *et al.* 2007 [12]	6	26	0	Ileal conduit, neobladder	ND	ND	ND	ND	DS	DS	DS	DS
DiMarco *et al.*2001 [6]	52	24	15	Ileal conduit	<6 months, all failed balloon in ≤1 year	NS	>1 cm predicted failure	NS	8–10	DS	DS	3–6
Kwak *et al.* 1995 [39]	18	>9	28	Ileal conduit	ND	ND	ND	ND	8	45 s 3 15 atm	10	4
Aliabadi *et al.* 1990 [40]	3	12	67	Sigmoid conduit	ND	ND	ND	ND	6–8	10 min DS DS	10	6
Beckman *et al.* 1989 [41]	5	22	60	DS	>3 months, less successful overall	ND	>2 cm less successful overall	ND	4–8	DS	7–10	4–8
Shapiro *et al.* 1988 [42]	37	>12	16	DS	NS	NS	NS	NS	4–10	1–2 min DS 17 atm	8–24	1–6
O'Brien *et al.* 1988 [43]	7	12	14	Ileal/colon conduit	ND	ND	ND	ND	4–6	DS DS 6–17 atm	DS	DS
Smith 1988 [44]	3	DS	66	Ileal conduit	ND	ND	ND	ND	DS	DS	DS	DS
Chang *et al.* 1987 [45]	8	4–48	50	Ileal conduit	Longer less successful overall	ND	Longer less successful overall	ND	5–8	DS 1 DS	8–16	5 weeks–3 months
Johnson *et al.* 1987 [46]	7	6–36	43	Ileal/colon conduit	>7 months, all failed	ND	ND	ND	4–10	30–60s/ 3 5 atm	5–16	Days to months

DS, details not specified; ND, predictor not discussed in publication; NS, predictor discussed but not significant.

Table 45.2 Outcomes following endoureterotomy of ureteroenteric strictures and predictors of success.

Study	Number of procedures	Mean follow-up (months)	Success rate (%)	Diversion type	Time to conduit creation vs procedure	Stricture location (left, right)	Stricture length	Stricture diameter	Balloon size	Duration/ cycles/ pressure	Stent size (French)	Stent duration (weeks)
Cold-*knife incision*												
Poulakis *et al.* 2003 [28]	43	38.8	60.5	Ileal conduit, colon conduit, neobladder	< 12 months likely to fail	NS	> 1.5 cm length likely failure	ND	NA	NA	8–12	6–12
Bierkens *et al.* 1996 [51]	2	12	100	Ileal conduit, continent diversion	ND	ND	ND	ND	NA	NA	12	6
Schneider *et al.* 1991 [52]	2	15	100	Ureterosigmoid	ND	ND	ND	ND	NA	NA	14	3–6
Cautery incision												
Lovaco *et al.* 2005 [24] (combined with balloon)	25	51	80	Ileal conduit, ureterosigmoid, neobladder	NS	NS	Greater length, likely failure	ND	DS	DS	6–7	6
Meretyk *et al.* 1991 [26]	14	28.6	57	Ileal/colon conduit	ND	ND	ND	ND	6–12	DS	8–22	3–28
Kramolowsky *et al.* 1988 [3]	7	13.5	71	Ileal conduit	ND	ND	ND	ND	10–12	DS	7–18	≥2
Electro-incision												
Milhoua *et al.* 2009 [23](Acucise)	2	23.2	50	Ileal conduit, neobladder	NS	NS	NS	NS	DS	DS	6–16	1.5–9
Touiti 2002 *et al.* [53] (Acucise)	6	16	50	Ileal conduit, neobladder, continent diversion	ND	ND	ND	ND	NA	NA	8–12	6
Lin 1999 *et al.* [54] (Acucise)	10	24	30	Ileal conduit, neobladder, continent diversion	NS	NS	NS	NS	NA	NA	10	6
Kabalin 1997 [55] (Acucise)	4	22	100	Ileal/sigmoid conduit,	ND	ND	ND	ND	NA	NA	10	6

Continued

Table 45.2 *Continued*

Study	Number of procedures	Mean follow-up (months)	Success rate (%)	Diversion type	Time to conduit creation vs procedure	Stricture location (left, right)	Stricture length	Stricture diameter	Balloon size	Duration/ cycles/ pressure	Stent size (French)	Stent duration (weeks)
Wolf *et al.* 1997 [13] (Acucise)	9	>36	39	Ileal conduit, neobladder, continent diversion	NS	Left more likely to fail	NS	NS	NA	NA	7–16	Varied
Preminger *et al.* 1997 [56] (Acucise)	9	DS	33	DS	ND	ND	ND	ND	NA	NA	6–14	5
Cornud *et al.* 1995 [57] (7Fr papillotome)	31	>12	71	Ileal conduit, neobladder	ND	ND	ND	ND	NA	NA	12–18	8
Holmium laser												
Milhoua *et al.* 2009 [23]	15	23.2	33	Ileal conduit, neobladder	NS	NS	NS	NS	DS	DS	6–16	1.5–9
Hibi *et al.* 2007 [58]	3	60.5	100	Ileal conduit, Indiana pouch	NA	NA	NA	NA	NA	NA	12	6
Watterson *et al.* 2002 [5]	24	22.5	71	Ileal conduit	NS	Left tended to fail	>1 cm tended to fail	NS	6	DS	12	6
Laven *et al.* 2001 [38]	19	20.5	57	Ileal conduit, neobladder, continent diversion	ND	Left tended to fail	ND	ND	NA	NA	DS	4–6
Singal *et al.* 1997 [30]	9	10.8	89	Ileal conduit	ND	ND	ND	ND	6–8	DS	12	4–6

DS, details not specified; NA, not applicable; ND, predictor not discussed in publication; NS, predictor discussed but not significant.

cutting modalities difficult. Success following wire-mounted cold-knife incision was 60.5% in the largest patient series at a mean follow-up of almost 39 months [28]. However, other experiences with this modality are quite limited in the literature. Electrocautery and holmium laser incisions were associated with similar mean success rates of 69% and 72%, respectively, though mean follow-up in the laser groups was shorter (17.9 vs 31 months) [3, 5, 23, 24, 30, 38, 58]. Both techniques allow for precise incision under direct visualization and hemostatic control with instrumentation familiar to most urologists. The electroincision group was mainly composed of Acucise treatments, though one study utilized a 7F electric papillotome [57]. The mean patency rates following electroincision (48%) were lower as compared to the other endoureterotomy modalities, but higher than balloon dilation alone [13, 23, 53–57]. As noted with primary balloon dilation, all studies utilized stents at the conclusion of the procedure. However, there was no consensus as to stent size (6–22F) and duration of stenting (1.5–22 weeks), though a 6-week period was commonly cited. Predictors of postoperative success included shorter stricture length (<1 cm) and right-sided stricture, though this was not uniform in all studies [3, 5, 13, 23, 24, 26, 28, 30, 38, 51–58]. Patients with poor ipsilateral renal function (<25% of total renal function) were unlikely to maintain patency after endoureterotomy [13].

Improvements in long-term patency rates following endoureterotomy may be contingent on a better understanding of the healing process of the ureter following incision. Unlike during open revision of the anastomosis, healing of the tissue occurs through secondary intention. Animal studies since the seminal reports by Davis note a predominance of myofibroblasts during the initial healing period, suggesting that healing may, in part, occur through wound contraction. Thus, the ureteral stent may serve as a mold during healing rather than as a scaffold for cell regeneration [59]. This finding may explain some reports that larger stent sizes were associated with improved outcomes [13, 60]. Increased collagen deposition resulting in fibrosis and scarring has also been observed in histologic specimens of failed ureteral stricture repairs [61]. Local injection of adjunctive triamcinolone may block collagen formation and subsequent scarring [25]. Though reported use during endoureterotomy is limited, steroid injection following stricture incision has been beneficial in select series [13, 26]. Ureteral stent duration may also affect healing. As noted in the included citations, a 6-week stent period was most commonly utilized, likely based on the findings of Davis. However, some porcine studies have noted more favorable histologic changes with a shorter stent duration, particularly for strictures greater than 2 cm [62]. Continued research is necessary to determine the optimal healing parameters following ureteral endoureterotomy.

Ureteral stenting

Chronic indwelling ureteral stent placement may be considered in patients with significant comorbidities or more likely in patients with a limited life-expectancy secondary to their primary disease. Review of 11 publications detailing 86 procedures utilizing various ureteral stents for primary ureteroenteric stricture treatment noted a success rate of 16.7–100% (mean 81%) at a mean follow-up of 6–22.4 months (Table 45.3) [12, 63–72]. Unlike temporary stent placement after balloon dilation or endoureterotomy, use of synthetic stents for primary treatment is not widely reported. One review of 20 procedures noted only a 45% long-term patency rate at a mean follow-up of 26 months. Even in successful patients, ongoing periodic stent exchange was required [12]. Repeated antegrade or retrograde insertion of the stent, particularly in patients with ileal conduits, can be difficult and may require novel techniques to aid with insertion [73]. The literature regarding use of the relatively new metallic double-pigtail stent for ureteroenteric strictures is also limited. In six cases of ureteroenteric stricture, placement of a metallic double-pigtail stent only had a 50% prolonged success as compared to 100% patency in 25 procedures for malignant obstruction [63]. The reported patency rates (mean 89.6%) for the short, permanent metal stents initially appeared more promising, but reports are characterized by small sample sizes and short follow-up (mean 12 months) [64–72]. In the largest series of 24 procedures, primary patency at 4 years was only 22.7% but increased to 56.7% after secondary interventions [64].

Complications

The reported complications following endoscopic management of ureteroenteric strictures are generally related to the surrounding anatomy and comorbid diseases. Similar to all urologic procedures, UTIs, and potential sepsis can occur following endoscopic manipulation, particularly in this high-risk population with colonized urinary diversions. Specific surgical complications directly associated with balloon dilation are few. Following endoureterotomy, in a series of 30 treatments, six major complications were reported, including one blood transfusion, three febrile UTIs, one sepsis, and one lacerated common iliac artery [13]. A series of 14 electrocautery procedures noted one ureteroenteric fistula that healed following prolonged stent placement [26]. Vascular injuries are a particular concern with electroincision endoureterotomy. In a multicenter trial of Acucise incisions, the authors noted common iliac artery

Table 45.3 Outcomes following primary stenting of ureteroenteric strictures and associated complications.

Study	Number	Type of stent	Time to exchange	Mean follow-up (months)	Success rate (%)	Diversion type	Required secondary procedure (%)	Worsening renal failure (%)	Stent migration (%)	UTI (%)
Synthetic stents										
Tal *et al.* 2007 [12]	20	17 10.2F nephroureteral/3 double-J	q3 month	26	45	Ileal conduit/ neobladder	41	15	5	0
Metallic stents										
Liatsikos *et al.* 2010 [63]	6	6F resonance	DS	6.8	50	DS	50	0	0	0
Liatsikos *et al.* 2007 [64]	24	6–8 mm self-expanding	NA	21	>50	Ileal conduit	62.5	0	0	0
Rapp *et al.* 2004 [65]	6	8 mm Wallstent	NA	10	100	Neobladder, ileal conduit	0	0	0	0
Wakui *et al.* 2000 [66]	1	6 mm Palmaz stent	NA	11	100	Ileal conduit	0	0	0	0
Palascak *et al.* 2001 [67]	10	8 *et al.* 10 mm Wallstent	NA	22.4	100	Ileal conduit	10	0	0	0
Daskalopoulos *et al.* 2001 [68]	3	6 *et al.* 10 mm Wallstent	NA	9	100	Ileal conduit, neobladder	0	0	33	0
Barbalias *et al.* 1998[69]	6	8 mm self-expanding	NA	12	100	Ileal conduit	25	0	0	0
Pollak *et al.* 1995 [70]	6	10 mm Wallstent	NA	6	16.7	Ileal conduit, neobladder	0	0	0	28.6
Reinberg *et al.* 1994 [71]	2	8 mm Wallstent	NA	12.5	100	Ileal conduit	0	0	0	0
Sanders *et al.* 1993 [72]	2	Palmaz stent	NA	7	100	Ileal conduit	0	0	0	0

NU = nephroureteral stent, DJ = double J ureteral stent, DS = details not specified, NA = not applicable; UTI, urinary tract infection.

injuries in 4% of patients and cautioned against the use of the device in ureteroenteric strictures [56].

In the normal anatomy, the distal ureteral segment is supplied laterally by branches of the inferior vesical artery. More cranially, the internal and common iliac arteries cross the ureter posteriorly. Following urinary diversion and reimplantation, the ureteral anatomy may be more distorted. Incisions anteriorly (12 o'clock) in the supine or dorsal lithotomy positions and posteriorly (6 o'clock) in the prone position are generally considered to be safe [27]. Further evaluation of adjacent vessels or bowel on preoperative CT imaging can be useful for surgical planning. Additionally, direct ureteroscopic visualization prior to visual or fluoroscopic incision or endoluminal ultrasonography may be used to detect arterial pulsations [35, 57].

The problems reported following prolonged ureteral stent placement are generally not vascular related (Table 45.3). *In situ* stents, particularly synthetic stents, are at risk for encrustation and obstruction with possible development of worsening renal function, urosepsis, and death [12, 74]. Even more common, chronic indwelling stents have been associated with fairly significant irritative voiding symptoms and discomfort in some patients [75]. Stent migration may also occur [12]. One series of 10 ureteroenteric strictures managed with metallic double-pigtail stents observed distal migration in 90% cases at a mean of 21 days (3–60) after placement. The authors hypothesized that the heavier weight of the metallic stent in combination with the increased motility of the bowel segment may have contributed to the occurrences [34]. However, this observation was not observed in other reports [63, 76]. Urothelial hyperplasia, stent migration, and encrustation are reported complications with the short, permanent metal stents [33]. Early hyperplasia is thought to be reactive secondary to the mechanical trauma exerted by the stent on the ureteral wall [64]. While endoscopy studies suggest that the hyperplasia may regress 4–6 weeks after stent insertion [66], urothelial ingrowth of the stent can result in complete occlusion of the ureteral lumen [77]. Secondary procedures within the metal stent, including balloon dilation, placement of a double-J stent or lithotripsy may be attempted as a salvage maneuver [63, 64, 69].

Postoperative follow-up

Given the variable reported success rates in the first few years following endoscopic management of ureteroenteric strictures, a regimented postintervention surveillance imaging protocol is necessary [24, 28, 38]. Both diagnostic imaging as well as functional renal studies should be obtained periodically to document lack of ureteral obstruction as well as to prevent loss of renal function [23]. We typically obtain excretory urography or renal scintigraphy at 3 months postoperatively (Figure 45.4). Clinical evaluation and renal scintigraphy are performed at 3–6-month intervals for the first 2–3 years. Additionally, renal ultrasonography and CT imaging are alternatively performed at these follow-up visits. The imaging modalities are spaced out further after the initial 2–3-year period. Repeated functional imaging, such as renal scintigraphy, excretory urography, antegrade nephrostography or loopography/neobladder cystography, are obtained if recurrence is suspected. Failures may be managed by a repeated or alternative endoscopic technique or treated with open revision.

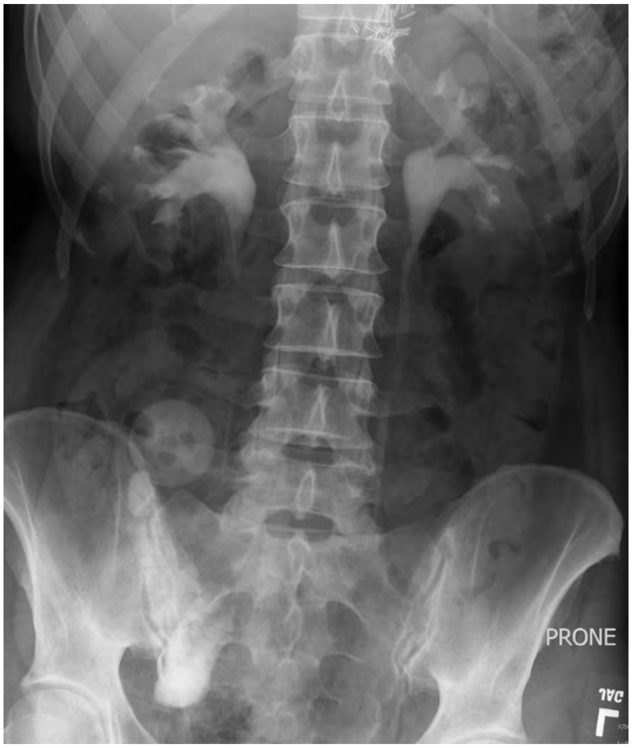

Figure 45.4 Excretory urography at 3 months after balloon dilation and holmium laser endoureterotomy reveals resolution of left ureteroenteric stricture.

Conclusions

The management of ureteroenteric strictures remains a challenging treatment dilemma. A variety of minimally invasive options is available due to advances in endoscopic instruments and these offer faster patient recovery. However, long-term success rates are less robust as compared to open surgical revision, and patients who fail endoscopic treatment may be at risk for slightly lower success rates and increased morbidity during later open surgery. Results following primary balloon dilation of ureteroenteric strictures have been disappointing. Endoureterotomy, regardless of the specific cutting modality, is the endoscopic procedure of choice for ureteroenteric strictures. Patients with shorter (<1 cm), right-sided strictures and preserved renal function may be more likely to have favorable long-term patency, though a clear determination of predictors for success is not possible. Newer material or designed ureteral stents may have utility in select patients, though complications of tissue ingrowth and obstruction are problematic. Further clinical trials involving use of adjunct therapy, such as steroid injection, as well as continued understanding of the causation and post-treatment healing process of the strictured ureter may aid in improving long-term outcomes.

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CHAPTER 46

Ureteroscopy: Ureteral Stents and Postoperative Care

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Introduction

Ureteroscopy (URS) is commonly used to treat urolithiasis and has become a standard endoscopic technique, replacing open stone surgery. This chapter will discuss analgesia and other medications utilized in the postoperative period. The use of ureteral stents and new and future technologies will also be discussed. Finally, the use of postoperative imaging following URS will be examined.

Ureteroscopy: outpatient versus inpatient management

The overwhelming majority of patients undergoing flexible or semi-rigid URS and intracorporeal lithotripsy are treated on an outpatient basis. Common indications for unplanned admission post procedure include flank or bladder pain not manageable with oral analgesics, fever, urinary retention, or significant hematuria. In addition, management of the uncommon procedural complications of ureteral perforation or avulsion account for a small percentage of admissions. In common with other planned outpatient procedures, late procedure start times and social circumstances precluding early discharge may result in overnight admission [1]. Table 46.1 lists techniques to increase the likelihood of maintaining URS as an outpatient procedure.

Emergency admission for renal colic with subsequent treatment with emergent URS can increase the likelihood of ongoing hospital stay post procedure [1]. Many urologists will have anecdotal experience of easier discharge post procedure when a patient who presents emergently with renal colic undergoes prompt URS treatment.

Prescriptions

Following any surgery, physicians typically prescribe medications for the postoperative period consisting of an antibiotic and/or analgesic. Following URS, there are many types of analgesics that can be prescribed and there is very little evidence regarding antibiotics in the postoperative period. In addition, two other types of medications can be prescribed to patients with urolithiasis. In the case of uric acid stones, patients may be prescribed a urinary alkalinizing agent to dissolve any remaining fragments. The second type is alpha-antagonists, which have been utilized to facilitate passage of fragments by relaxing ureteral smooth muscle [2–4] and to help alleviate postoperative ureteral stent symptoms [5–8].

Antibiotics

Patients are often prescribed antibiotics following surgery to prevent infection. The decision on whether to prescribe antibiotics should balance the risk of infection with the risk of adverse effects of antibiotics and the induction of antibiotic-resistant bacterial strains. In cases where the risk of infection is high, the risk of complications such as *Clostridium difficile* colitis justifies the

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Table 46.1 Technique to increase likelihood of outpatient ureteroscopy (URS).

Thorough discussion with patient and family preoperatively regarding post-URS clinical course and expectations
Operative start time during morning or early afternoon
Prompt surgical intervention in patients presenting emergently with renal colic
Dose of nonsteroidal anti-inflammatory, such as ketorolac, at completion of procedure
Bladder drainage at completion of procedure
Avoidance of routine ureteral stenting for uncomplicated URS
Appropriate stent length and diameter
Consideration of anticholinergic medications for stent-related bladder spasms
Consideration of alpha-blocker medication for stent discomfort

use of antibiotics. In cases where there is a low risk of infection, then the utility of postoperative antibiotic prophylaxis becomes less clear.

There is good evidence to give antibiotics at the time of surgery. A randomized trial of 113 patients were administered either levofloxacin 250 mg po 60 min prior to URS or no antibiotics [9]. The rate of bacteriuria in the control group was 12.5% compared to 1.8% in those receiving levofloxacin. The study did not examine the use of antibiotics in the postoperative period.

The American Urological Association guidelines recommend preoperative antibiotic prophylaxis in all patients undergoing URS with either a fluoroquinolone or trimethoprim (or alternatively with an aminoglycoside, penicillin, amoxicillin/clavulanate, or cephalosporin) for less than 24 h duration. Oral ciprofloxacin was shown to be equivalent to intravenous cefazolin, with a 9.1% infection rate in 77 patients undergoing urologic procedures (42 of these were URS) [10].

As mentioned above, there is no guideline or strong evidence in the literature for using antibiotic prophylaxis in the postoperative period.

Analgesics

Analgesics for renal colic and passage of fragments

The options for treating postoperative pain range from the commonly used analgesics, which target pain at the central nervous system, to medications that target specific receptors in the urothelium. The literature lacks suggestions for analgesics specifically after URS, but the passage of fragments after intracorporeal lithotripsy can be accompanied with pain very similar to that found in renal colic.

Alpha-antagonists for stone expulsion

Alpha-antagonists inhibit smooth muscle contraction and have been used extensively in the treatment of benign prostatic hyperplasia. In the endourologic world, they have found two further purposes: as medical therapy to facilitate stone expulsion and to relieve ureteral stent symptoms. The theory underlying these observations is relaxation of ureteral smooth muscle to allow ureteral stones to pass, and in the case of stents, to prevent ureteral spasm. This is done by inhibiting selective alpha(1)-adrenergic receptors and reducing ureteral contractility [11, 12].

Medical expulsive therapy has been found to increase the stone passage rate as well as hasten the time to stone passage, and reduce pain, narcotic requirement, and hospitalizations for renal colic [13, 14]. A meta-analysis evaluating 693 pooled patients found a greater likelihood, compared to placebo, of stone passage when they were given an alpha-blocker [risk ratio (RR) 1.54, 95% CI 1.29–1.85] or calcium channel blocker with steroids (RR 1.90 95% CI 1.51–2.40) [3]. The number needed to treat in this analysis was only 4, indicating that this is a worthwhile and effective treatment for ureteral stones. Some studies have produced an even higher rate of stone expulsion (RR 2.93, 95% CI 1.15–7.45) in patients administered tamsulosin [15].

Most studies have evaluated stones in the distal ureter, but what about proximal ureteral stones? A study evaluating stone passage rate in patients administered placebo versus tamsulosin also found an increased stone passage rate, as well as quicker stone passage time in those given tamsulosin with proximal ureteral stones [16]. Although the drug helped with spontaneous stone passage (35.7% vs 30%, $P = .04$), this effect was more profound in stones smaller than 5 mm (71.4% vs 50%, $P < .001$). Stones between 5 and 10 mm tended to migrate into the distal ureter more readily in those patients given the alpha-blocker (39.3% vs 18.7%). It would appear that alpha-antagonists also help spontaneous stone passage of proximal ureteral stones, and in the case of stones larger than 5 mm, help them migrate into the distal ureter where rigid URS is more easily performed.

Are all alpha-blockers equally effective? A randomized placebo controlled trial evaluating tamsulosin, terazosin, or doxazosin found equal rates of stone passage among all medications [17]. Different alpha-blockers, including the alpha (1A) selective antagonist, silodosin, and the alpha (1D) selective antagonist, naftopidil, have also been shown to inhibit ureteral contractility and reduce ureteral pressure in a dog model, and may be useful in expulsion of ureteral stones [18]. Naftopidil has been used clinically for stone expulsion with positive results, yielding a spontaneous stone passage rate of 90% versus 27% in controls for an increased probability of stone expulsion of 5.26 (95% CI 2.30–12.02) [19].

Prescribing alpha-antagonists may help facilitate passage of stone fragments following URS.

Analgesics for stent-related pain

Phenazopyridine and oxybutynin have been administered orally in an attempt to relieve stent-related symptoms. A trial involving 60 patients randomized to phenazopyridine, oxybutynin, or placebo recorded the following measures: narcotic use, flank pain, suprapubic pain, urinary frequency, urgency, dysuria, and hematuria [20]. There was a trend, although statistically insignificant due to the small group numbers, for a reduction in narcotic usage in the oxybutynin group. Phenazopyridine significantly reduced the amount of hematuria patients had on postoperative day 1 compared to placebo. Perhaps a larger study would discern if either of these medications would be helpful in relieving stent symptoms.

Alpha-blockers

Patients randomized to alfuzosin following URS and stent insertion had significantly less narcotic use, less overall pain in the back and groin area, less flank pain during urination and less urinary frequency compared to patients given placebo [21]. Tamsulosin also produced similar significant results in other placebo-controlled prospective trials of patients undergoing ureteral stent placement following URS [5, 8, 22]. It would appear that alpha-blocker administration post ureteral stent insertion is an excellent way to prevent and relieve symptoms.

Botulinum toxin A

It is unknown exactly from where stent symptoms originate. There is evidence that the junction of the ureter and bladder play a role. One trial randomized patients who had a ureteral stent post URS to three injections of botulinum toxin A into the bladder around the ureteral orifice or no injection [23]. Stented patients with botulinum toxin A experienced significantly less pain than controls and required less narcotic usage. This lends evidence to the theory that detrusor muscle spasm around the intramural ureter is a cause of ureteral stent pain. Most interestingly, the stent used in this study was a multilength ureteral stent [23]. There is a belief that more significant material in the bladder leads to more significant symptoms, but there are no randomized clinical data to support this anecdotal belief. The future and feasibility of delivering botulinum toxin A to patients with ureteral stents cannot be foreseen, but there is good evidence that it helps relieve stent symptoms.

To stent or not to stent?

The decision must be made at the end of each URS on whether or not a ureteral stent should be placed. The absolute indications to leave a ureteral stent are listed in Table 46.2 [24]. There is good evidence from randomized clinical trials suggesting that patients without ureteral stents fare better than those who receive a ureteral stent [1, 25–28]. Few unstented patients post URS require surgical intervention for ureteral obstruction, with the majority managed by improved pain control. In addition, the vast majority of patients treated on a "stentless" basis have no obvious preprocedure predictor of subsequent flank pain or obstruction. Supporting the role of postprocedure ureteral stenting is the study by Borboroglu *et al*. in which a risk for admission for flank pain post URS of 7.4% was reported in the unstented group versus a 0% readmission rate in the stented group [29]. However, the overall cohort of unstented patients had substantially less flank pain. Although the avoidance of a postprocedure ureteral stricture is commonly encountered in the literature as a justification for ureteral stenting, the meta-analysis of randomized controlled trials by Nabi *et al*. indicates no difference in stricture rate between those stented and not stented [30].

While some studies have shown fewer symptoms and less pain in those patients without a stent, a meta-analysis found a trend towards fewer urologic

Table 46.2 Indications for ureteral stenting post ureteroscopy (URS) (from Chew and Denstedt [24] with permission).

Ureteral perforation intraoperatively
Ureteral dilation greater than 10F (either coaxial or balloon dilator)
Significant ureteral edema due to stone (e.g. impacted stone)
Failure to advance the ureteroscope due to a narrow ureter or ureteral orifice and in preparation for a subsequent URS after 7 days
Infected urinary system with an obstructing system
Large stone burden with many fragments still to pass
Solitary kidney

complications in patients who received a stent following URS [31]. Some of the trials included in the analysis found no difference in complication rates between stented and unstented patients, but there was an overall 4.5% reduction in rate of complications in those patients who underwent placement of a stent following URS (95% CI 1.8–7.3%, $P = .001$). When a more stringent random effects model was applied, however, this difference was not statistically significant (4.1% risk difference, 95% CI 1.8–10.1%, $P = .175$). At present in the literature, there is no significant difference in outcomes between patients who receive a ureteral stent compared to those who do not receive a ureteral stent following URS.

Which stent is most comfortable?

Once a decision to place a stent is made, the question becomes which stent to use. This question is often asked, but there are no conclusive data as to which commercially available stent is the most comfortable for patients. There are a variety of factors that are taken into consideration, including the softness (durometer) of the stent, its design, and its size (both length and diameter).

Intuitively, softer stents would be expected to be more comfortable than harder stents; however, randomized trials have shown no difference between soft and hard stents in terms of urinary symptoms, pain, time away from work, or sexual dysfunction utilizing the Ureteral Stent Symptom Questionnaire (USSQ) [32], the only validated tool for evaluating ureteral stent symptoms [33, 34]. In one trial, patients randomized to a "stiffer" stent (>64A; Percuflex® stent; Boston Scientific, Natick, MA, USA) were compared to patients who received a softer stent (<64A; Contour™ stent; Boston Scientific;) [33]. No differences between the groups were seen at 1 and 4 weeks in terms of urinary symptoms, overall body pain, work performance, or general health index. Lennon *et al*. randomized patients to firm polyurethane stents or a softer Sof-Flex™ stent (Cook Medical, Bloomington, IN, USA) [34]. Patients with firmer stents had a higher rate of dysuria, and renal and suprapubic pain; however, there was no significant difference in the degree of bladder inflammation, stent encrustation, urgency, frequency, nocturia, or hematuria. The only shortcoming of this study is that patients were not evaluated with a validated stent symptom questionnaire, the USSQ.

More recently, Lingeman *et al*. and the Comfort Study Team utilized the USSQ to assess whether patient comfort was best with a short loop tail stent, a long loop tail stent, a Percuflex Plus stent, or a Polaris stent (Boston Scientific) [35]. All kidney curls were identically composed of a 6F pigtail curl and the Percuflex Plus stent consists of the same material and coil in the bladder end. The distal ends differed in the other three stents: the short loop tail stent consisted of two loops that were 5 cm long and 3F in diameter compared to the long loop tail stents which also had two loops but these were 8 cm long and 3F in diameter. The Polaris stent is a dual durometer stent with a stiffer renal curl to prevent migration, but a softer curl in the bladder in an attempt to decrease bladder irritation and symptoms. Two hundred and thirty six patients were randomized to receive one of the stents following uncomplicated URS and were administered the USSQ at baseline, 4 days after stent placement, and 5 days after stent removal. There were no statistically significant differences in pain scores between any of the stent groups. There was decreased use of narcotics in the first 1–3 days after stent placement in the short loop tail stents, but this was insignificant at the 4-day mark. Most notably, the USSQ may not have been administered at the correct time as all patients had the most severe discomfort symptoms on postoperative day 1. By day 4, when the USSQ was administered, all symptoms had subsided. Despite the fact that the authors developed their protocol to test the stents at day 4, there may have been a significant difference if it were measured at day 1. This finding supports the theory that stent symptoms occur from irritation of the trigone of the bladder. A softer material that also has less mass in the bladder may help alleviate ureteral stent-related symptoms.

Stent length relating to discomfort

Even though there are no clear data to support the use of one type of stent over another, there are good data that longer stents that protrude further into the bladder produce more symptoms. Choosing the correct length stent will significantly help reduce patient stent symptoms. Stents that cross the midline of the bladder result in significantly more dysuria, urgency, and irritative voiding symptoms than stents that do not cross the midline [36]. Long stents are associated with excess material in the bladder and, therefore, presumably with more bladder irritation, but do not result in excess stent length in the kidney [36]. Fluoroscopic studies of stented patients show that, with motion, the stent tends to bow in the mid and proximal ureter and the excess length slides in and out of the bladder at the ureterovesical junction, with relatively little movement in the kidney [37]. Flank pain was not affected by stent length, but there is good evidence that negative bladder symptoms are increased in patients with longer stents compared with those who are stented with a stent of the correct length.

How is the correct stent length chosen? This question has baffled many a urologist and many methods have been described, including measuring patient height, torso length, intravenous urography, and direct ureteral measurement. One study found that direct intraoperative measurement of ureteral length was better than patient height at correlating with the correct length of stent [38]. Another study evaluated several anthropometric factors, including patient height, body mass index (BMI), and distances from the acromium process (shoulder) to the head of the ulna (wrist), olecranon process (elbow) to the head of the ulna, xiphoid process to the pubis, umbilicus to the pubis, and anterior iliac spine to the anterior iliac spine [39]. Ureteral length intraoperatively with a 5F ureteral catheter was measured and it was found that height, xiphoid process to pubis distance, and the shoulder to wrist distance all correlated with ureteric length. Ho *et al*. recommended a 22-cm stent for patients of 149.5–178.5 cm in height, but they did not study patients outside this height range [40]. To date, there is no standard accepted method of determining the most appropriate length of ureteral stent.

Drug-eluting ureteral stents

One of the newest technologies is to release drug to the immediate tissues surrounding the stent via a drug-eluting ureteral stent. Similar to drug-eluting coronary artery stents to help prevent arterial restenosis, a drug could be loaded into the bulk material of a stent or into the coating to elute over time. The advantage of local drug delivery is the high concentration of drug in the tissues surrounding the stent. To deliver similar high concentrations of drug to local tissues would require very high systemic levels, which would increase the risk of systemic side effects; with drug-eluting technology, the systemic levels are practically negligible, yet a high concentration of drug is delivered to the local area.

Drug-eluting ureteral stents have been used to tackle two problems: infection and stent symptoms. The first drug-eluting ureteral stent available on the market involved the use of the antimicrobial triclosan that is used in over 800 commercial products. It is not an antibiotic *per se*, but inhibits fatty acid synthesis which is necessary for building cell membranes. A triclosan-eluting ureteral stent (Triumph™ stent; Boston Scientific) was shown to be effective against common bacteria *in vitro* [41, 42] and against *Proteus mirabilis* in a rabbit model [43]. However, in patients who required a long-term stent, the triclosan-eluting ureteral stent did not reduce stent-related infections [44]. This stent has never been approved in the USA due to Federal Drug and Administration (FDA) fears that it may induce antibiotic-resistant organisms, although triclosan has never been shown to induce resistance.

In order to determine which drug would help with stent comfort, a randomized study assessed whether intravesical administration of oxybutynin, lidocaine, or ketorolac would improve stent symptoms compared to a saline control in patients who were stented immediately before shock-wave lithotripsy [45]. The nonsteroidal anti-inflammatory, ketorolac, was found to significantly reduce stent-related flank pain compared to controls and the other agents. A ketorolac-eluting ureteral stent (Lexington™; Boston Scientific) was developed to elute its medication over 90 days, with the majority of the drug released within the first 30 days. The safety and tissue levels of ketorolac was first tested in a porcine model of 92 animals either stented with a ketorolac-eluting ureteral stent or administered oral ketorolac as a control [46]. Plasma levels of ketorolac were approximately 11-fold lower in the animals that received a ketorolac-eluting stent compared to the control group that received oral ketorolac. The highest level of ketorolac in the ketorolac-eluting stent group was found in the ureteral tissue, the target area for this medication to reduce symptoms. This study highlights that a drug-eluting ureteral stent can be used to deliver high levels of drug to the local area while minimizing systemic levels and, therefore, reducing adverse effects.

A clinical trial randomized 276 patients to receive either a ketorolac-eluting ureteral stent (13% drug by weight) or a control nondrug-eluting ureteral stent following URS [47]. The primary end-point was to reduce the number of interventions, including unscheduled physician contact, early stent removal, or change in analgesic medications. The authors reported no difference in primary (9.0% ketorolac loaded vs 7.0% control, $P = .66$) or secondary (22.6% ketorolac loaded vs 25.2% control, $P = .67$) intervention rates. However, further analysis demonstrated that the mean pain pill count at day 3 was lower in the ketorolac-loaded stent group than in the control group ($P < .05$). In addition, a greater percentage of patients with ketorolac-loaded stents used no or limited pain medication compared to controls (32% vs 22%, $P = .057$). Age was found to play a role in stent discomfort with patients over 45 years old in both cohorts using less pain medication than their respective younger cohorts. In addition, in patients younger than 45 years, those with ketorolac-loaded stents used fewer pain pills on days 1–4 compared to those with control stents ($P < .05$). This study suggests a potential benefit of ketorolac but may have been underpowered to statistically confirm this trend. This was the first drug-eluting ureteral stent used clinically in an attempt to improve patient comfort.

In the future, drug-eluting ureteral stent technology will potentially be used not only to treat discomfort, but also infection, encrustation, or other urologic diseases such as prostatitis, interstitial cystitis, or upper tract transitional cell carcinoma.

Biodegradable ureteral stents

Ureteral stents typically require a secondary procedure for removal if a suture tether is not used. This can add cost, inconvenience, and discomfort for the patients. In addition, if a patient is lost to follow-up and if there is any miscommunication about the fact that the patient has a stent, this can lead to a "forgotten" stent potentially requiring several surgeries for removal or even loss of the renal unit [48–51]. There have been case reports of mortality stemming from forgotten ureteral stents [52]. Attempts to reduce retained stents have included a stent registry [53, 54]. A stent without a suture tether that does not require cystoscopic removal has also been developed using a high-powered magnet catheter that is inserted into the bladder to bind a steel bead attached to the distal end of the stent for removal [55]. This low-cost alternative to cystoscopy offers a safe "blind" removal of the ureteral stent in any type of setting under local anesthetic.

Perhaps the holy grail of preventing a retained stent is one that would degrade over time. The properties of an ideal biodegradable stent are that it must function to provide drainage like a plastic stent, be easy to deploy, be radio-opaque, maintain its integrity for at least a certain amount of time in order for ureteral edema, etc. to subside, but not overstay its welcome and take too long to degrade. Furthermore, it should be comfortable, biocompatible to surrounding tissues, and degrade in a fashion that does not obstruct the distal ureter.

Lingeman *et al*. performed a phase I clinical trial to evaluate the Temporary Ureteral Drainage Stent (TUDS; Boston Scientific) in 18 patients [56]. All stent material was extruded within 4 weeks with only one stent prematurely migrating into the bladder at day 1. A phase II trial of the TUDS stent evaluated 88 patients following URS and the stents were eliminated from the ureter at a median of 8 days and eliminated completely from the body at a median of 15 days [57]. By 30 days, 84% (74 of 88) of the stents had completely degraded. Unfortunately, in three patients, stent fragments remained at 3 months and these patients required surgical intervention for their removal. For the majority of patients (78.2%), the stent was effective at providing upper tract drainage for at least 48 h postoperatively, the targeted time to define success. Due to the manufacturer's concerns about retained fragments, the TUDS stent is no longer commercially available.

A more recent degradable stent composed of L-lactide, glycolide, and copolyester components similar to those found in absorbable sutures has been developed and tested in a porcine model (UripreneTM; Poly-Med Inc, Greenville, SC, USA) [58]. It has been developed to degrade within 2–3 weeks with all stents being completely eliminated from the body by week 4 in a porcine model [59]. The stent was biocompatible on histology and did not result in any hydronephrosis in comparison to the control biostable stents. Drainage was also superior to that with control stents, as seen on weekly intravenous pyelograms (IVPs). The safety of this stent has been tested and proven in an animal model of ureteral stenting. Human trials will determine its true degradation time and if there is any improvement in comfort. Hopefully, the development of biodegradable stents will aid in reducing stent symptoms and infection, and avoid the forgotten stent syndrome.

Postoperative imaging following ureteroscopy

Routine imaging postoperatively remains controversial despite over a decade of studies reported in the era of small-diameter, semi-rigid and flexible ureteroscopes. Multiple authors, in the setting of either a randomized controlled trial of stented versus unstented URS or a retrospective case series, have demonstrated a low risk of post-URS obstruction[1, 25, 27, 29, 60–77] (Table 46.3). Given the high stone-free rate for URS of upper tract calculi, the major indication for postprocedure imaging is the detection of a ureteral stricture, with a risk in uncomplicated cases of less than 5%. Predisposing factors for ureteral stricture post URS include preoperative factors such as chronic stone impaction, reduced renal function, coexistent ureteral stricture on the treated side, and complete ureteral obstruction [68, 77, 78]. In addition, intraoperative factors such as significant ureteral edema, ureteral trauma, or ureteral perforation are established risk factors for ureteral stricture and mandate close long-term radiologic follow-up [68, 78]. Indeed, the retrospective case series of Roberts *et al*. reported a 24% incidence of ureteral stricture in patients with chronic ureteral stone impaction of greater than 2 months [78]. However, previous iatrogenic ureteral perforation from previous stone manipulation was encountered in the majority of stricture cases. Regardless, the more contemporary series of Beiko *et al*. reported that all four cases of ureteral stricture post URS occurred in patients with identifiable preoperative risk factors [68].

Adiyat *et al*. retrospectively compared the incidence of ureteral stricture between a high-risk group of complicated URS cases (n = 56) and a cohort of uncomplicated URS patients undergoing routine stone surveillance imaging (n = 158) [77] (Table 46.3). In common with other authors, cases of complicated URS, consisting of those with encountered impacted stone, need for ureteral balloon dilation, or ureteral perforation, demonstrated a substantial risk of ureteral stricture of 5.3%. In contrast, long-term radiologic surveillance in the uncomplicated URS group (mean follow-up of 10.2 months) revealed no ureteral strictures. The predisposition of a

Table 46.3 Ureteroscopy (URS): Follow-up imaging.

Study	N	Stone location	URS type	Selective vs routine imaging	Imaging modality	Mean duration follow-up (months)	Postoperative hydronephrosis (%)	Postoperative surgical intervention (%)
Schatloff *et al.* 2010 [61]	60	Ureter	R	Routine	U/S or CT	1	N/A	1.7
Manger *et al.* 2009 [74]	289	Renal and ureter	R & F	Routine	U/S	1	9.3	2.8 (0.3 stricture)
Breda *et al.* 2009 [75]	51	renal	F	Routine	U/S	1	N/A	0 stricture
Macejko *et al.* 2009 [76]	92	Renal and ureter	R & F	Routine	NCCT	3 (mean)	N/A	N/A
Adiyat *et al.* 2009 [77]	214	Renal and ureter	R & F	Complicated URS (n =158) Uncomplicated URS (n = 56)	NCCT	16.06 10.21	10.7 5.6	5.3 stricture 0 stricture
Elashry *et al.* 2008 [71]	4512	Distal ureter	R	Routine	U/S, IVP	7.6 (mean)	N/A	0.23 stricture
Ibrahim *et al.* 2008 [25]	220	Distal ureter	R	Routine	U/S, CT	25	N/A	1.4 stricture
Karadag *et al.* 2008 [72]	268	Ureter	R	Routine	IVP, U/S	27.4	1.1	0.7 stricture
Pearle *et al.* 2008 [73]	35	Renal (LP)	F	Routine	NCCT	3	N/A	5.7 repeat URS
Portis *et al.* 2006 [69]	58	Renal and ureter	F	Routine	NCCT	1	N/A	1.7 stricture
Geavlete *et al.* 2006 [70]	2436	Ureter	R	N/A	N/A	56	N/A	0.1 stricture
Beiko *et al.* 2003 [68]	68	Renal and ureter	R & F	Routine	U/S	5.6	8.9	5.9 stricture
Weizer *et al.* 2002 [64]	241	Renal and ureter	R & F	Routine	IVP, CT or U/S	5.4	12.3	1.2 stricture
Bugg *et al.* 2002 [65]	77	Renal and Ureter	R & F	Routine	IVP, CT or U/S	1.8	16	2.6 stricture
Chen *et al.* 2002 [66]	60	Ureter	R	Routine	KUB and U/S	1	0	0 stricture
Sofer *et al.* 2002 [67]	330	Renal and ureter	R & F	Routine	IVP, U/S	>1.5	N/A	2.4 stricture (8 of 330)
Borboroglu *et al.* 2001 [29]	91	Distal ureter	R	Routine	CT, IVP or U/S	1.8	0	0 stricture
Netto *et al.* 2001 [63]	295	Ureter	R	Routine	KUB and U/S	N/A	N/A	0.7 stricture (2 of 295)
Denstedt *et al.* 2001 [27]	58	Ureter	R & F	Routine	U/S	3	0	0 stricture
Hosking *et al.* 1999 [1]	59	Ureter	R	Routine	IVP or U/S	2	N/A	0 stricture
Karod *et al.* 1999 [62]	131	Ureter	R	Routine	IVP	2	11	0.8 stricture

Numbers of patients, where reported, consist of patients with upper tract urolithiasis undergoing URS intervention.
R, semi-rigid ureteroscope; F, flexible ureteroscope; U/S, ultrasound; CT, computed tomography; NCCT, noncontrast CT; IVP, intravenous pyelogram; KUP, kidneys, ureters, bladder.

ureteral stricture from ureteral balloon dilation remains controversial, with some authors suggesting this is a risk factor [68, 77], while others do not [1]. Again, further evidence is needed to support selective imaging limited to patients with known risk factors for postoperative ureteral stricture development.

Multiple authors advocating limited radiologic evaluation in the early post-URS period have based this recommendation on the presence or absence of pain as an indication for imaging [72]. The majority of studies assessing the etiology of pain after URS demonstrate a substantially greater likelihood of a retained stone fragment rather than a stricture being responsible [65, 77]. Bugg *et al*., as advocates of limited post-URS imaging, reviewed the chance of postoperative obstruction when preoperative obstruction and postoperative pain are combined [65]. The authors reported that patients with preoperative obstruction and postoperative pain had a 67% chance of having residual fragments and a 50% chance of residual obstruction. In contrast, 96% of patients without preoperative obstruction and no postoperative pain had no persistent obstruction or residual fragments. However, the risk of missing silent obstruction remains, as 25% of asymptomatic patients had residual stone fragments or obstruction. The authors suggest that the ready availability of renal ultrasound could substitute for IVP or CT in the detection of obstruction for physicians not comfortable with avoidance of routine imaging post URS.

The correlation of pain with post-URS ureteral obstruction has been questioned by Wiezer *et al*. who caution urologists regarding the risk of silent hydronephrosis [64]. In this retrospective case series from the Duke University group, the absence of pain was noted in seven patients who presented postoperatively with silent hydronephrosis (of a total of 241 patients). This translates into a 3% risk of renal functional impairment in patients undergoing URS if relying only on symptoms to prompt imaging. In common with Wiezer *et al*., Manger *et al*., in a retrospective case series of 289 patients with available post-URS sonography, report that 27 (9.3%) had sonographic evidence of hydronephrosis [74]. Of these 27 patients with hydronephrosis, 14 were asymptomatic and 13 reported ipsilateral flank pain. From this series, the risk of silent obstruction is significant (4.8%), with the authors calculating the number needed to diagnose one case of hydronephrosis as 18 asymptomatic patients post URS. Further, the negative and positive predictive values of ipsilateral flank pain for hydronephrosis were 94% and 35%, respectively. In conflict with this large percentage of patients with post-URS hydronephrosis (providing evidence for routine post-URS imaging) is the small number of patients in this series with asymptomatic hydronephrosis who eventually required surgical intervention.

The majority of studies assessing imaging post URS have relied on IVP or CT scans to rule out obstruction. In contrast, Manger *et al*. demonstrated the value of renal ultrasound post URS as a screening study [74]. Given the increasing recommendations to limit medical radiation exposure in patients combined with the ready availability of sonography, the authors recommend renal ultrasound as the imaging study of choice post URS in asymptomatic patients to rule out obstruction [79, 80].

Conclusions

URS remains an effective outpatient tool in the treatment of stones. There is good evidence for preoperative antibiotic prophylaxis, but no evidence for antibiotics following URS. Postoperative use of ureteral stents is not supported for every routine, uncomplicated URS. If a stent is to be left, however, the proper length stent should be inserted to reduce stent symptoms. Ketorolac, oxybutynin, or an alpha-antagonist may help reduce stent-related symptoms. Drug-eluting ureteral stents may be used in the future to reduce stent symptoms. Botulinum toxin A may be a future drug to be eluted from stents to reduce symptoms. Alpha-antagonists may also be prescribed postoperatively in an attempt to facilitate spontaneous expulsion of stone fragments. Postoperative imaging should include ultrasonography to evaluate for hydronephrosis and obstruction regardless of symptoms.

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CHAPTER 47

Ureteroscopy Complications

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Introduction

Ureteroscopy (URS) has become a major technique for the diagnosis and treatment of lesions involving both the ureter and the intrarenal collecting systems. Both the technique and instrumentation of URS have evolved dramatically and its indications have expanded in a proportional manner [1, 2].

The development of smaller semi-rigid or flexible ureteroscopes and of modern energy sources has significantly decreased URS-related incidents and complications [3, 4]. The decline in the incidence of ureteral injury has been particularly significant. The intraoperative complication rate, most notably represented by the ureteral perforation rate, has decreased to less than 5%, and long-term complications, such as stricture formation, occur with an incidence of 2% or less [1, 5]. However, despite significant technologic advances, surgical misadventures still occur, some of which have lasting consequences [4–6]. Careful attention to instrument selection and surgical technique are critical for reducing untoward events related to URS. Ideally, any complications associated with URS should be related to the underlying pathology rather than to treatment.

Classification

Although a formal classification system for secondary URS lesions has not yet been established, most authors define them by severity and time to occurrence. Complications can be divided into intraoperative, and early or late postoperative, and then each of these categories can be further subdivided into major and minor complications.

Most URS complications are minor, do not require specific measures or can be solved endoscopically [6]. The major complications, even though of reduced incidence (<1%) [5], may be serious and can cause significant morbidity.

Although most complications occur intraoperatively, their sequelae often appear in the early or late postoperative period. However, certain events that occur during URS will require supplementary maneuvers in order to complete the procedure; these are usually classified as intraoperative incidents. A few complications arise primarily postoperatively, such as infection or urinary retention [5].

Predisposing factors

There have been several studies of the factors that may be associated with an increased risk of complications. In a study of 322 cases, Schuster *et al*. noted a significant association between postoperative complications and kidney stones, operative time, and decreased surgeon experience, as well as a trend toward significance for the type of ureteroscope used [7]. In multivariate logistic regression models, ureteral perforation remained highly correlated with the operative time when controlling for the other factors. More recently, Abdelrahim *et al*. reported that symptoms present for more than 3 months, a negative history of schistosomiasis, a positive history

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of ureteral surgery, stones above the ischial spines, stones of 5 mm in width, a dilated proximal ureter, kidneys that failed to excrete contrast, and involvement of a junior urologist were factors associated with a statistically significant higher incidence of intraoperative complications [8]. Similarly, El-Nahas *et al*. demonstrated that significant factors for unfavorable results were proximal ureteral stones, URS performed by surgeons other than experienced endourologists, stone impaction, and stone width (relative risks 4, 2.5, 1.8, and 1.2, respectively) [9].

In their evaluation of 105 URS holmium:YAG lithotripsy procedures, Leijte *et al*. demonstrated a complication rate of 12.4% [4]. They concluded that greater surgeon experience is significantly correlated to higher success and lower complication rates in URS holmium:YAG laser lithotripsy. Sex, stone location, stone size, and age did not significantly influence complication or success rates.

T Complication rates remain low even in select cases, such as children or pregnant women [1]. The risk of major complications to the mother and fetus for urologists who are experienced with URS procedures should be less than 2% [10].

Intraoperative incidents

Difficulties of ureteral access

Technologic advances in ureteroscope design have facilitated access to the upper urinary tract. However, difficulties in ureteral orifice and intramural ureter negotiation or ureteroscope progression may still be encountered. Access failure prohibits URS and represents a significant incident. Trauma to the ureteral orifice or intramural mucosa can increase the difficulty of subsequent URS. This incident occurs in 1.6% of cases [7] and may be associated with musculoskeletal abnormality and contractures, narrowing of the ureter secondary to stricture or extrinsic compression, obstruction caused by edema or impacted stone, and iatrogenic ureteral lesions [11].

The ureteral orifice may be difficult to visualize or catheterize in men with a large prostatic median lobe or in women with cystocele. Several options have been described to facilitate the guidewire insertion, such as placing the guidewire over a ureteral catheter, emptying the bladder, using a flexible cystoscope and hydrophilic guidewires, or URS placement of the guide [12]. In some cases, even if the ureteral orifice can be visualized and a guidewire placed, the negotiation of the orifice with the semi-rigid ureteroscope may be difficult to accomplish. Attempting to straighten the ureter with a super-stiff wire or by using a flexible ureteroscope may be helpful. In selected cases, the URS approach through the ureteral orifice may be helped by performing intramural ureter dilation. Balloon dilation permits faster, less forceful access through the ureteral orifice into the ureter and upper tract, which is particularly important if multiple passes of the ureteroscope are necessary [13]. Although routine ureteral dilation was necessary for URS using the early larger (>10F) ureteroscopes, this principle has been questioned with the advent of smaller caliber rigid and flexible ureteroscopes [14]. Facilitating the ureteral orifice approach by using two guidewires represents a simple, efficient, and inexpensive way of avoiding ureteral orifice dilation.

The ureteral access sheath allows easier introduction of the ureteroscope in cases that require multiple passages. Experimental studies have confirmed secondary ureteral ischemia, although no long-term clinical sequelae, such as ureteral strictures, have been attributed to it [15].

Previously reimplanted, ectopic, and duplicated ureters may be difficult to access as well. Pelvic or retroperitoneal surgery or radiation therapy can fix the ureter in the deep pelvis. This situation significantly increases the risk of perforation, particularly when a rigid instrument is used. Likewise, guidewire or ureteroscope advancement may be difficult in cases of ureteral stricture or tortuosity. These conditions are most frequently subsequent to surgical interventions or related to a physiologic narrowing of the lumen. In these cases, using a hydrophilic guide may help the maneuver. Difficulties in advancing a guidewire may be overcome by inserting it under direct visual control, without trying to push it through the obstacle.

Another reason for access failure is the inability to overpass a calculus with the guidewire. This can be negotiated by instillation of intraureteral lidocaine jelly [11]. Usually, in such situations, a ureteral catheter may be introduced up to 1.5 cm below the stone. A hydrophilic guidewire is then inserted along this catheter, which can easily pass by the calculi. Afterwards, the catheter is pushed above the obstacle and the hydrophilic guidewire is replaced with a regular one. If this maneuver fails, the ureteroscope may be advanced up to the stone, thus advancing the wire under visual control.

In case of failure, the guidewire may be placed under antegrade URS control. If calculi cannot be overpassed by the guide when placed antegradely or retrogradely, a percutaneous nephrostomy followed by resumption of retrograde maneuvers after 2 weeks is the most recommended option.

Correct patient selection, as well as the use of appropriate technique and devices, can reduce the risk of this incident. Small semi-rigid or flexible ureteroscopes facilitate access to the upper urinary tract. Percutaneous nephrolithotomy and extracorporeal shock-wave lithotripsy (ERCP) remain valid options in cases of a failed URS approach.

Equipment failure

Although the introduction of smaller ureteroscopes and miniature accessory instruments has increased the maneuverability of URS, these instruments are fragile, displaying a high prevalence of malfunction (see Video 47.1). Poor vision or damage to accessory instruments can result in patient injury.

Abdel-Razzak and Bagley reported two cases among 222 patients in which the procedure was stopped due to equipment failure, with iterative procedures being necessary [16]. In a series of 322 patients, Schuster *et al.* reported six incidents secondary to equipment failure [7].

Ureteroscope fracture during endoscopic procedures (Figure 47.1) was reported as having a very low incidence [11]. It can be avoided by careful handling of the rigid and semi-rigid ureteroscopes, during which the visual field must keep a perfectly round shape. When the endoscopic field shifts to a crescent-shaped image, instrument breakage is imminent.

A fractured flexible ureteroscope with locked deflection *in situ* requiring ureteroscope sectioning and open extraction was reported by Anderson *et al.* [17]. Guidewire breakage may occur due to deterioration induced by lithotripsy devices. When in direct contact, the holmium:YAG laser may cause ancillary instrument fracture, and the resultant fragments may require URS extraction. Balloon dilator breakage may lead to iatrogenic lesions of the ureteral wall, including perforations, urinary extravasations, or bleeding. This event may follow rapid balloon inflation or exceeding the recommended pressure, and can be avoided by insuring a gradual and carefully monitored pressure increase.

The real incidence of complications related to equipment malfunction is probably underestimated. Many of these events may be avoided by appropriate maintenance and handling during sterilization, storage, and use [5]. Flexible ureteroscopes are particularly fragile, thus requiring specific protection measures. During flexible URS, accessory instruments must be introduced without proximal end deflection in order to avoid deterioration of the working channel. The operator must be accustomed to the devices and instruments, operation mechanisms, and usual settings of lithotripsy equipment. In case of malfunction, the instruments should be replaced, or, if not possible, the procedure must be stopped immediately, in order to avoid major complications.

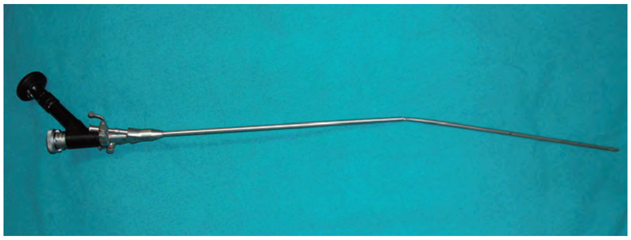

Figure 47.1 Fractured semi-rigid ureteroscope.

Retained basket

This incident occurs in about 0.5% of cases. The forced retraction of the basket in this situation may lead to an extremely serious complication, represented by the rupture of the ureteral wall in close contact with the calculi and eventual ureteral stripping.

In the majority of cases, this complication can be solved endoscopically, by unsheathing the basket followed by ureteroscope withdrawal [6]. Afterwards, the endoscope is inserted along the basket, and stone lithotripsy between the wires is performed until the extracting device is released (see Video 47.2).

Proximal calculus migration

Until recently, proximal calculus migration, which occurs in between 5% and 10% of cases [5], was considered an intraoperative incident and a significant cause of treatment failure. However, due to new treatment alternatives (and especially flexible ureterorenoscopy), ascending migration of the stone is no longer considered an intraoperative incident.

The risk of ascending migration depends on the initial location of the calculus, the type of energy source, as well as the degree of dilation of the upper urinary tract. Before the widespread use of flexible URS, this incident required subsequent treatment with ESWL or nephrolithotomy. Nevertheless, proximal migration of a calculus does prolong anesthesia and operative time, and may submit the patient to a second procedure.

The type of lithotripter has a significant impact on the risk of proximal migration, with higher rates after pneumatic and electrohydraulic lithotripsy than after holmium:YAG laser lithotripsy. Prevention of ascending migration may be achieved by placing the patient in a reverse Trendelenburg position or by minimizing the irrigation pressure.

Different devices have been developed to reduce the risk of proximal migration, e.g. balloon catheters or special devices (including Stone Cone, Stone Catcher, Accordian), which allow occlusion of the ureteral lumen above the stone [18]. A similar occlusion may be achieved using Backstop gel. This is a water-soluble, self-forming, polymeric plug with reverse thermosensitive properties, applied proximal to the stone, which can be dissolved in saline and thereby removed at the end of the procedure.

Ureteral stent malposition

Ureteral stent malposition has a low frequency and is most likely to occur due to ureteral stenosis or tortuosity. It can be avoided by proper placement of the guidewire in the pyelocalyceal system and advancement under fluoroscopic guidance (see Video 47.3).

Intraoperative complications

Intraoperative complications of URS have reported incidence rates between 0.5% and 20% [7, 13, 19–21]. Most are minor and can be treated in a conservative manner by ureteral stenting without long-term consequences. These minor complications include false passage, mucosal abrasion, irrigation fluid extravasation, and ureteral wall perforation. Major complications are rare, with an incidence of 1.5–5%.

Mucosal abrasion

Mucosal abrasion occurs to some degree during all URS procedures (see Videos 47.4 and 47.5). Secondary bleeding and ureteral wall edema can reduce endoscopic visibility and maneuverability of the instruments. Postoperatively, minimal ureteral lesions may cause obstruction secondary to edema or clots.

After 248 procedures using large-caliber instruments (9.5F or 11.5F), Francesca *et al*. described a 24% incidence of ureteral mucosa lesions [3]. By comparison, the use of small-caliber instruments (6–7.5F) in 49 procedures was associated with a 6% incidence of mucosal abrasion.

Appropriate technique may decrease the incidence of ureteral abrasion and diminish its consequences. If multiple ureteroscope passages are required, the use of a ureteral access sheath can prevent a traumatic ureteral mucosa lesion.

Bleeding

Bleeding secondary to URS is usually minor. It often occurs due to either ureteral orifice trauma or lesions produced during guidewire advancement, or calculi handling or fragmentation. Bleeding reduces visibility during the procedure, and in extremely rare cases, its intensity may require the procedure to be stopped or additional measures taken to control it.

Blute *et al*. emphasized the fact that reduced visibility secondary to minor bleeding was the most frequent reason a repeat procedure was necessary [21]. Nevertheless, this complication was considered the primary complication in only 0.3% of the cases. In a series of 290 patients, Abdel-Razzak and Bagley reported a 2.1% incidence of bleeding severe enough to require the procedure to be stopped [16]. None of these patients required transfusion. Based on 1000 procedures, Grasso reported a 0.8% and 0.2% incidence of prolonged intra- and postoperative bleeding, respectively [22].

In a study of 37 patients on anticoagulant treatment, Turna *et al*. described no increased risk of hemorrhagic adverse events or decreased stone-free rates related to flexible ureterorenoscopy and holmium:YAG lithotripsy [23].

Thermal lesions

The use of heat-producing energy sources during URS may affect nearby tissues, causing various lesions from small mucosal defects to large necrotic areas.

The electrohydraulic lithotripter is associated with a significant temperature rise and high risk of ureteral thermal lesions. Basar *et al*. reported two perforations (1%) from electrohydraulic lithotripsy in a series of 207 ureteroscopies [24].

Some lasers are associated with a risk of thermal lesions. The Nd:YAG laser has a deep penetrability of 5–6 mm and therefore must be used with extreme caution in order to lower the risk of harming adjacent organs [25]. The energy produced by the holmium:YAG laser is absorbed by water, thus leading to thermal lesions in the range of 0.5–1 mm. Based on a trial of 598 flexible URS procedures, four complications were attributed to the holmium:YAG laser, of which one was a case of ureteral perforation and three of laser fiber fracture [26]. Although ureteral stenting alone may be sufficient in such cases, late complications can still occur [11]. Thermal lesions can be prevented by avoiding contact between the laser probe and the ureteral mucosa, and by placing the probe parallel to the wall.

Ureteral false passage

False passages may develop during insertion of the safety guidewire (Figure 47.2, Video 48.6), ureteroscope, or another instrument. These lesions consist of mucosal perforation without complete ureteral wall crossing (Figure 47.3). Often, false passages may occur when an attempt is made to overpass the stone with the guidewire.

Blute *et al*. reported a false-passage incidence of 0.9% in 346 URS procedures [21], while Grasso found an incidence of 0.4% for the same complication in a series of 1000 patients [22]. As for perforations (see below), the incidence of these events may be underestimated due to a failure to recognize the lesion during the procedure (see Video 47.7).

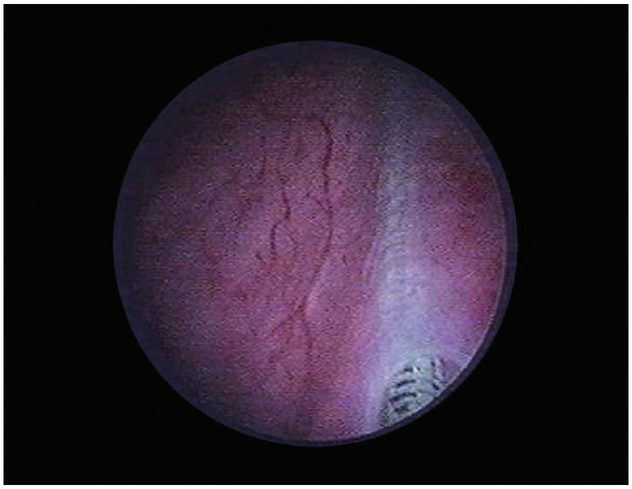

Figure 47.2 Submucous false passage produced with the guidewire.

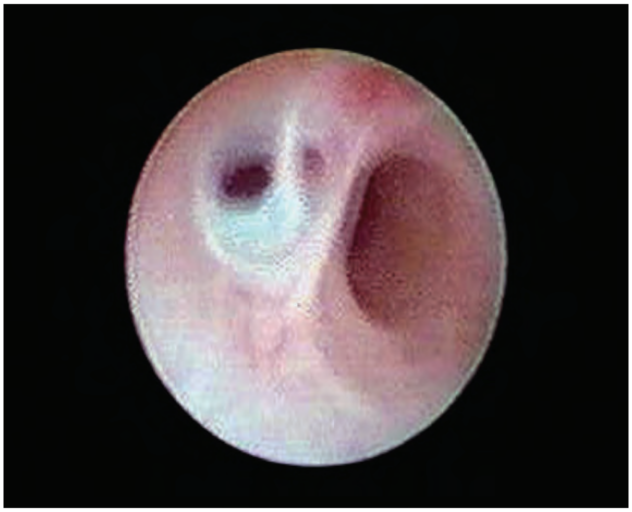

Figure 47.3 Ureteral false passage.

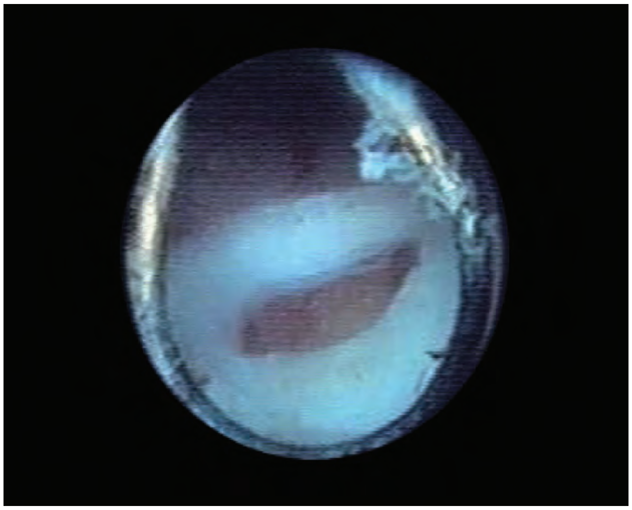

Figure 47.4 Ureteral perforation during trans-ureteroresection of transitional cell carcinoma.

Lytton *et al*. reported complete occlusion with ureteral necrosis following a false passage produced all along the ureter that occurred while advancing the ureteroscope [27].

Developing a false passage during guidewire insertion can be suspected if it is either difficult or impossible to advance. If there are doubts concerning the existence of ureteral mucosa lesions, contrast may be injected to confirm the guidewire position within the pyelocalyceal system. The appearance of periadventiceal extravasation of the contrast can certify the false passage and consequently the guidewire must be repositioned intraluminaly. Sometimes, this maneuver can only be performed under direct URS visual control [28].

Ureteral false passages produced during guidewire advancement can lead to serious lesions if later they act as passages for advancing catheters and other instruments of larger caliber. However, sequelae of false passages are usually minor. In most cases, double-J stenting for 1–2 weeks is enough. Small false passages that are limited to the mucosa can be treated in a conservative manner, without stenting.

Ureteral perforation

Perforations include small lesions that occur while advancing the guidewire, the laser fibers, or other accessory instruments on the one hand, and significant lesions caused by the tip of the ureteroscope or by calculi propulsion through the ureteral wall on the other (see Videos 47.8 and 47.9) .

The risk of ureteral perforation increases in cases of sinuosity, periureteral fibrosis (secondary to surgery or irradiation), or fixed calculi, or if there is sudden patient movement. General anesthesia is preferable to regional anesthesia for these patients, and an appropriate curarization is especially needed.

Perforation is recognized by observing the breach in the ureteral wall or the periureteral fat tissue (Figure 47.4). Careful handling of the ureteroscope under direct visual control may reduce this type of injury.

The incidence of ureteral perforation ranges from 0% in more recent studies involving flexible ureteroscopes [22] to as high as 17% in earlier series [29]. Stoller and Wolf assessed studies published between 1984 and 1992 and, based on 5117 URS procedures, reported a 6.1% incidence of ureteral perforation [30]. Stoller reported 24 perforations after 156 procedures (15.4%), 19 of which occurred in cases in which high-caliber ureteroscopes were used (12.5F) [14]. By contrast, Abdel-Razzak and Bagley reported a 1.7% rate of ureteral perforations using 8.5–10.8F ureteroscopes [16]. Comparing the results of conventional ureteroscopes (9.5–11.5F) to those obtained using the low caliber ones (6–7.5F), Francesca *et al*. reported a ureteral perforation rate of 11.2% and 2%, respectively [3]. More recent studies have shown a less than 2% incidence for this complication [5]. Grasso reported no ureteral perforations in a series of 1000 URS procedures [22].

The reduction in incidence of ureteral perforation has occurred with the availability of small ureteroscopes and precise energy-releasing lithotripters, i.e. laser and pneumatic lithotripters rather than the older electrohydraulic ones, as well as increasing experience. However, ureteral perforation continues to represent a significant complication, carrying a major risk of ureteral stenosis.

The differentiation between large perforations and partial avulsions is difficult, but their treatment is largely similar. In most cases, ureteral perforation requires stenting for 2–6 weeks, and only exceptionally is open surgery or laparoscopy necessary. In a series of 1575 patients, Jeromin and Sosnowski reported 29 ureteral lesions, of which 20 were minor ureteral mucosa lesions, five were minimal perforations necessitating ureteral stenting, and four were severe perforations for which open surgery was mandatory [31]. In case of failed ureteral stenting, percutaneous nephrostomy or antegrade stent insertion is necessary. If the percutaneous or retrograde approaches are impossible, open surgery is required.

After the intervention, it is advisable to perform a careful follow-up of the patient in order to identify ureteral stenosis or fistula secondary to iatrogenic lesions.

Urinary extravasation

Urinary extravasation can occur following ureteral wall lesions and leads to retroperitoneal urinoma. According to several studies, the incidence of urinary extravasation is 0.6–1% [5]. However, because retrograde intraoperative pyelography is not a recommended routine procedure, it is possible that the real incidence of this complication may be underestimated. The degree of extravasation is directly related to the parietal lesion size as well as to the moment of perforation.

Small quantities of liquid extravasation do not usually have clinical significance. Nevertheless, important extravasations may have disadvantageous effects. Absorption of hypotonic irrigant may cause volume overload, hyponatremia, and hemolysis. Using saline solutions during URS may prevent this complication. Also, to avoid calyceal rupture or perforation, an appropriate irrigation pressure is recommended.

The existence of an associated urinary infection may cause retroperitoneal abscesses. Some studies have underlined the fact that urinary extravasation causes periureteral fibrosis. In case of significant extravasation, ureteral stenting or percutaneous nephrostomy may ensure an adequate drainage and ureteral healing without sequelae.

When postoperative urinary extravasation is suspected, intravenous pyelography exploration is mandatory (Figure 47.5).

Submucosal calculi migration

Stone fragment migration at the ureteral mucosa level (Figure 47.6) represents a complication for which the therapeutic approach remains controversial. Even though exteriorization of a stone fragment through the ureteral wall does not have long-term consequences, its stabilization at the submucosal level may cause

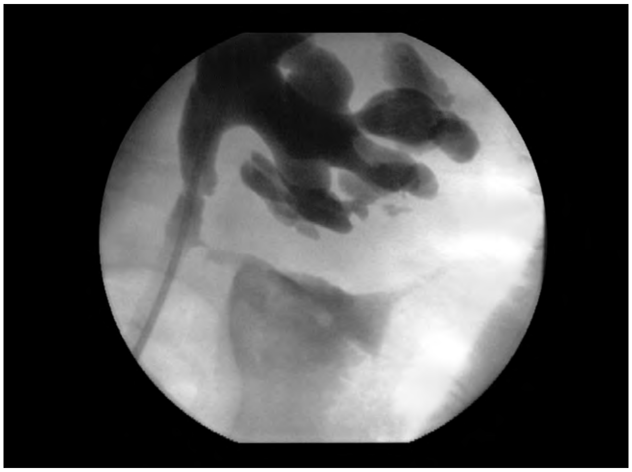

Figure 47.5 Ureteral perforation with contrast extravasation.

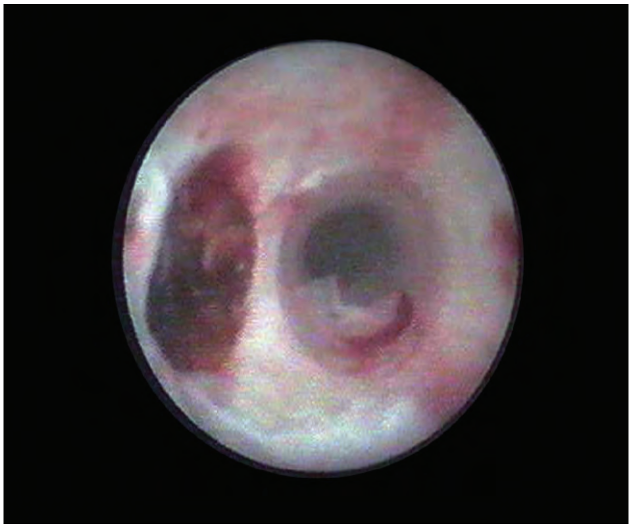

Figure 47.6 Stone fragment migrated through a ureteral wall perforation.

granuloma formation and subsequent ureteral stenosis. The extraction of these calculi is difficult (see Video 47.10), as it may lead to ureteral perforation, retroperitoneal urinoma, and secondary periureteral fibrosis.

Dretler and Young reported four cases of granuloma induced by calcium oxalate stone fragments imbedded in the ureteral wall during URS lithotripsy for cases of ureteral stenosis untreatable by ureteral dilation [32]. Grasso *et al*. revealed a high-risk of stenosis related to stone fragments imbedded in the ureteral wall less than 4 mm from the lumen [33]. It is for this reason that endoluminal ultrasound evaluation is recommended, and that fragments located less than 4 mm from the ureteral lumen should be extracted, while deeper migrated fragments may be left on-site with minimum risk of further complications. In many cases, the submucosal stone fragments can be identified from bulges seen on the ureteral wall during endoscopy, and no endoluminal ultrasonography is necessary.

Calculi stabilized at the submucosal level can be extracted by laser incision followed by prolonged ureteral stenting. When this approach is not possible, surgical resection of compromised ureteral segments is required.

When the obstruction occurs during the postoperative period, computed tomography (CT) may establish the presence of stone fragments near to the ureteral lumen or along the stent.

Extraureteral calculi migration

The incidence of extraureteral calculi or stone fragment migration is between 0.5% and 3.2% [11, 34–36]. Extruded stone fragments may be the result of an improper endoscopic technique associated with the presence of some predisposing factors [37]. Ureteral wall edema, poor blood supply in the injured zone, microtrauma of the ureteral mucosa, a high intraluminal pressure secondary to the irrigating fluid, and compression of stone fragments by the ureteral stent placed after the procedure are thought to be involved.

Extraureteral calculi migration does not usually cause clinical complications or require treatment [35, 36]. Despite this fact, the presence of a continuity solution within the ureteral wall may induce stenosis development or other late complications. Any attempt to advance the ureteroscope or to introduce different instruments through the breach in order to extract the stone fragments may widen the ureteral wall gap. When lithiasis is associated with urinary infection, a retroperitoneal abscess may develop.

Extraureteral calculi migration requires radiologic highlighting of fragments and the patient should be informed in order to prevent further potential diagnostic confusion [38]. Postoperative follow-up involves ultrasonographic monitoring in order to verify the absence of obstruction as well as upper urinary tract repercussions.

Intussusception

Ureteral intussusception during URS is a rare complication. It can occur in both directions and is more accurately an avulsion of the inner mucosal lining of the ureter [39]. This complication can follow forceful extraction of large ureteral calculi, in association with ureteral polypoid transitional cell carcinoma (TCC) after retrograde pyelography or URS.

Surgical resection and ureteral reimplantation are necessary to correct this complication.

Ureteral avulsion

Ureteral avulsion is a major intraoperative complication involving extensive lesions caused by ureteral elongations that lead to its rupture in the area of minimal resistance, most commonly the proximal third of the ureter (see Video 47.11).

Though very rare (0.2–1.5% incidence) [6, 13, 21], it is the most serious complication. The first two cases were reported by Hart in 1967 [40] and Hodge in 1973 [41], and both had occurred after difficult handling of ureteral stones using the basket probe. In a review by Stoller and Wolf assessing more than 5000 URSs, a 0.3% incidence of this complication was reported [30], but in another evaluation of 1059 patients between 1992 and 1998, no ureteral avulsions were reported [22].

Disregarding the basic rules of URS, such as inappropriate equipment, lack of ureteral orifice dilation when needed, misuse of baskets for calculi extraction, and visual deficiency during lithotripsy is of particular importance in the development of this complication. The major risk factors are use of multiple wire baskets, especially for stones larger than 1 cm, and large distance between calculi and ureteral orifice [42]. This has limited the use of baskets for stone fragment extraction in numerous centers. The risk of ureteral avulsion is also much higher during rigid URS [43]. Another potential factor involved in ureteral avulsion is the pre-existence of ureteral pathologic areas, either following a certain condition or secondary to previous endoscopic or open surgery procedures.

Ureteral avulsion can usually be diagnosed immediately it occurs during the procedure by recognizing the tubular structure engaged after the extraction maneuvers (Figure 47.7). Sometimes, the lesion can be identified through retrograde pyelography performed for suspicion of a ureteral lesion. In this case, there is complete extravasation of the contrast and no opacity in the ureteral segment above the lesion. On rare occasions,

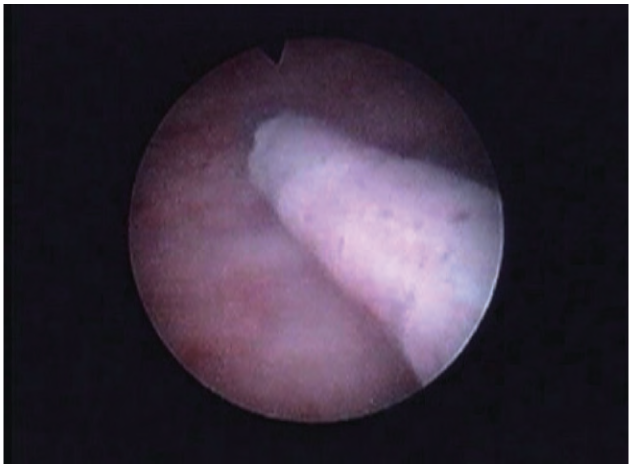

Figure 47.7 Ureteral segment tractioned into the bladder after ureteral stripping.

late diagnosis may be established due to fever, lumbar pain, palpable lumbar tumor, retroperitoneal urinoma symptoms, or abscess secondary to urine extravasation [43]. In these cases, diagnosis must always be confirmed by ultrasound, CT, intravenous pyelogram (IVP), or retrograde pyelography.

Intraoperative recognition of this complication demands immediate surgery. If the lesion is diagnosed late or if the patient requires additional preparation or stabilizing measures, percutaneous nephrostomy is recommended until the definitive treatment is performed.

Open surgery and laparoscopy are the methods of choice in treating ureteral stripping, the objective being restoration of the ureteral continuity. Despite this fact, there are no distinct guidelines regarding the optimal treatment alternatives for this complication. When making a therapeutic choice, the patient's age, renal function, lesion location, and ureteral defect length must be considered. Some authors suggest that when ureteral continuity can be re-established by using the guidewire, ureteral stenting for a few months with the aim of secondary healing of the ureteral wall, may be attempted. However, this involves an important risk of ureteral stenosis.

If the distal ureter is affected by the lesion, the therapeutic choice may be ureteroneo-cystostomy. Sometimes, reimplantation may require "psoas hitch" or "Boari flap" procedures, or combinations of the two, but such techniques are limited to ureteral lesions located below the pelvic brim. Middle ureteral lesions may be treated through end-to-end anastomosis over the ureteral stent, providing the ureter is not devitalized. In case of complete ureteral avulsion from the ureteropelvic junction (UPJ), the first treatment of choice is pyeloplasty.

If tissue loss is important, autotransplantation (especially in younger patients) or ileum interposition may lead to good results [43, 44]. In the long-term, ureteroplasty using an ileum segment may lead to metabolic disorder. Another alternative to extensive lesion reconstruction may be appendix interposition [45]. Kidney autotransplantation is a viable alternative, even in cases with a short remaining ureter, and the long-term results are superior to those of ileum interposition. Very rarely, nephrectomy may be the most appropriate option in patients with a normal contralateral kidney as attempting to preserve the renal unit will bring additional risks [6].

Ureteral avulsion can be prevented by using an appropriate technique. Surgical experience, observing the basic URS rules, using small caliber instruments, avoiding basket stone removal, performing fragmentation before extraction, and obtaining a good visualization during lithotripsy are all important. Basket extraction of proximal or middle ureteral stone fragments must be performed with extreme caution. The recommended option is to use triradiate grasping forceps which allows calculi release in case of difficult extraction. If the stone cannot be safely removed, lithotripsy is recommended so that the resulting fragment can be easily extracted.

Partial ureteral avulsion

Partial ureteral avulsion is a rare complication which causes less severe sequelae than ureteral avulsion. If a safety guidewire has not been inserted during the procedure or if lesions cannot be overpassed, percutaneous nephrostomy with antegrade stenting is indicated [30].

Early postoperative complications

Infection/sepsis

Seeding infectious pathogens in the upper urinary tract during the procedure is a major cause of secondary urinary tract infections (UTIs). Likewise, handling potential infected calculi may induce sepsis. Using a high irrigation pressure in cases of UTI leads to bacteremia.

The incidence of fever during the immediate postoperative period is relatively high, but this does not always reflect UTI or bacteremia. The chemically-induced sterile kidney inflammation is sometimes the reason for fever [30]. In a series of 346 URSs, Blute *et al*. reported fever over 38°C as the most frequent complication (6.4%) [21]. According to Abdel-Razzak and Bagley, postoperative fever has an incidence of 1.2–1.3% [16].

Preoperative antibiotics reduce the risk of postoperative infections and fever. Jeromin and Sosnowski reported a 22% incidence of fever in a group of patients in whom preoperative antibiotics were only administered in complicated cases, the UTI being diagnosed in 3.7% of cases [31]. Francesca *et al*. [3] diagnosed UTI in 22.5% of patients previously subjected to retrograde URS using high-caliber ureteroscopes and in only 4% of patients for whom small-caliber semi-rigid ureteroscopes were used [3]. No clear explanation was given for this difference.

The incidence of post-URS sepsis is low. Schuster *et al*. described a UTI incidence of 1.2% and a 0.3% sepsis rate [7], while Stoller *et al.* reported a 2% rate sepsis [14]. The literature does not establish a precise difference between infection and sepsis, which leads to extremely heterogeneous reports.

Even though sepsis or UTI may occur despite sterile preoperative urine, sterilization before the procedure must still be performed. Urine culture-based antibiotics are mandatory before the procedure, although prophylactic antibiotics for patients with sterile urine culture are controversial.

As already mentioned, reducing the irrigation pressure is important for preventing urinary infections and bacteremia, especially in case of infected lithiasis, although the pressure must be maintained high enough to allow good visibility. Lowering the upper urinary tract pressure can be achieved by using a ureteral access sheath [46], an angiographic catheter, or by emptying the collecting system via the ureteroscope. Additionally, continuous or discontinuous bladder drainage may help maintain a low pressure during URS.

Obstruction

Ureteral mucosa lesions induced by instruments maneuvered inside the upper urinary tract may lead to obstruction due to local edema, clot formation, and ureteral spasm. Ureteral stenting at the end of the procedure decreases the rate of this complication. The reported incidence of post-URS renal colic ranges from 4% to 9% [16, 22]. Harmon *et al*. reported a renal colic rate of 3.5%, with replacement of the ureteral stent being necessary in 2.6% of cases [13]. Obstruction is usually self-limiting and treatable by conservative measures.

In case of persistent pain, imaging evaluation is necessary to confirm the obstruction, determine its degree, and establish its location. Ureteral stenting may lead to remission of symptoms.

Vesicoureteral reflux

Vesicoureteral reflux may occur after URS, even if no ureteral dilation was previously performed. In a series of patients, Ritcher *et al*. highlighted a 10% reflux rate 24 h after URS was performed with a 13.5F ureteral orifice dilation [47]. Resolution of the reflux was demonstrated in all cases by repeating the cystography after 2 weeks. Other studies have reported the presence of reflux in 5–10% of patients 3–20 months after the procedure, most of whom having undergone intramural ureter dilation [14]. Using small-caliber semi-rigid or flexible ureteroscopes without ureteral orifice dilation may reduce the incidence of reflux.

Late postoperative complications

Late complications are extremely rare due to equipment improvement and growing endoscopic experience.

Ureteral stenosis

The incidence of post-URS stenosis ranges from 0% to 4%. These strictures (Figure 47.8) may occur as a consequence of ureteral trauma induced by the endoscopic procedure or following stone impaction leading to periureteral liquid extravasation, mucosal lesions, and wall ischemia, or even thermal lesions caused by endoluminal lithotripsy [19, 48].

Ureteral perforation at the level of impaction was considered the main risk factor for postoperative stenosis. Though Stoller *et al*. reported a global stenosis rate of 3.5% [14], this rose to 5.9% in patients with ureteral perforation. Based on a retrospective study in 21 patients with ureteral impacted calculi for more than 2 months, Roberts *et al*. reported a 24% complication rate after an average period of 7 months from the initial URS [48].

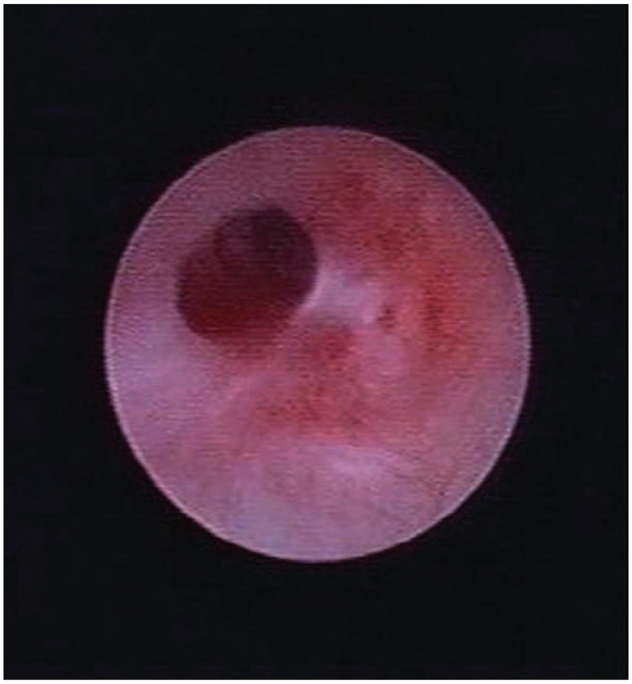

Figure 47.8 Ureteral stenosis following ureteroscopy.

The incidence of this complication has been significantly reduced following the minituarization of ureteroscopes, as well as equipment and technique improvement. Initial studies using 9.5–12.5F ureteroscopes reported postoperative stenosis rates higher than 4% [21], while in more recent evaluations the secondary stenosis rates in patients for whom low-caliber semi-rigid or flexible ureteroscopes were used were under 1% [3, 13, 16].

Some authors have assumed that use ofa ureteral access sheath may induce postoperative stenosis. Delvecchio *et al.* found only one case of ureteral stenosis after 71 URSs using this device [49].

All types of intraureteral lithotripsy have the potential to generate thermal energy that can causes mucosal lesions and eventually strictures. It appears that the highest temperatures occur with electrohydraulic lithotripsy. Additional factors such as previous irradiation lead to increased necrosis or a risk of ureteral devascularization after endoscopic handling. This event may eventually induce ureteral stenosis.

Due to the reduced rate of ureteral stenosis after the introduction of the newer generation ureteroscopes, some authors questioned the need for an imaging investigation as part of the follow-up. In the reassessment of 183 URS cases, Karod *et al*. found no ureteral obstructions among the 110 asymptomatic patients [50]. This complication was only found in one of the 21 patients with postoperative symptoms. Based on these data, the authors claim that post-URS imaging evaluation can be avoided in asymptomatic patients with no intraoperative lesions. However, Weizer *et al*. reported a 3.7% rate of asymptomatic obstruction and recommended routine imaging evaluation 3 months after the procedure in order to avoid potential complications of undiagnosed ureteral obstruction [51].

Careful handling of the ureteroscope, accessories, and stones, and minimizing ureteral trauma are important in the prevention of secondary stenosis. Performing dilation of narrowed ureteral areas can decrease the perforation rate as well as the risk of late ureteral stenosis. Ureteral stenting and repeating the procedure after 7–10 days can facilitate the URS approach.

In case of ureteral perforations, a double-J stent for 2–3 weeks may decrease the risk of stenosis [14]. The literature provides little data concerning the specific stenting time in these situations.

Postoperative ureteral stenosis requires endoscopic evaluation of the location and length of the affected area (see Video 47.12). The first treatment option is endoureterotomy as these strictures are generally nonischemic and short [52]. Balloon dilation followed by ureteral stenting is another viable alternative. Long ischemic strictures or cases of failed endoscopic treatment can benefit from open surgery or laparoscopy.

Persistent vesicoureteral reflux

Persistent ureteral reflux has a very low incidence, and most commonly occurs with ureteral dilation, ureteral orifice incision, or intramural tract lesions.

Vesicoureteral reflux rarely requires surgical treatment. Sterile, low-degree reflux in adults is usually of no consequence. Consequently, there is no need for routine radiologic reflux evaluation after URS [30].

Persistent vesicoureteral reflux may be treated by endoscopy, submucosal Teflon, bovine collagen or autologous fluid fat injection, or by creating different antireflux mechanisms [53].

Complications of ureteroscopic management in upper tract transitional cell carcinoma

URS treatment of upper urinary tract tumors was initially considered an option in patients with solitary kidneys, renal failure, bilateral TCC, or significant medical comorbidities. More recently, this approach was also indicated for renal preservation in patients with normal contralateral kidneys and small volume focal low-grade upper tract TCC [54].

The complications described in the literature are either similar to those related to other URS procedures or specific to upper urinary tract TCC treatment. The main differences are the incidence and mechanism of occurrence of ureteral perforation and stricture. With this procedure, there is a 2% risk of ureteral or pelvic perforation due to technical errors involving endoscopes, guidewires, baskets, and/or laser fibers. Grasso and Bagley reported no perforations in 101 patients treated for upper tract TCC [55]. However, Elliott *et al*. [56] and Martinez-Pineiro *et al*. [57] reported two and four perforations, respectively.

Perforation while using the holmium:YAG or Nd:YAG laser can occur if the power settings are too high, the ablation too deep, or the laser is directed to the ureteral or pelvic wall rather than to the tumor. The laser fiber tip should always be visualized a few millimeters beyond the distal end of the ureteroscope and directed at the tumor under visual control [54, 58].

Once a perforation is intraoperatively diagnosed, discontinuation of the procedure should be considered in order to prevent tumor seeding. Most perforations can be treated conservatively by ureteral stenting. Larger perforations may require percutaneous drainage or even nephroureterectomy [54].

The incidence of ureteral strictures after treatment of upper tract TCC has ranged from 5% to 25% [58]. The risk of scarring and stricture formation is higher after extensive laser ablation of the tumor and adjacent ureter. Chen and Bagley reported ureteral stricture formation in 12 of 139 patients (8.6%) [54]. Elliot reported six ureteral strictures in a group of 54 patients, three or whom were treated with the Nd:YAG laser and three with electrocoagulation [56].

Strictures discovered during the follow-up period must be biopsied to rule out a malignant stricture.

Another significant complication of the upper urinary tract tumor endoscopic approach is incomplete resection. The incidence is higher for tumors over 1.5 cm or located in the lower pole of the kidney. In these cases, a second treatment could be an option for low-grade tumors. In high-grade, large or multifocal tumors, nephroureterectomy should be considered.

Tumor cell seeding during URS were assumed due to the elevated irrigation pressure. However, studies on significant numbers of patients with upper urinary TCC treated by nephroureterectomy after URS did not reveal any malignant cell seeding [59].

Andrews and Segura described a renal pelvic explosion during URS fulguration of a papillary TCC, probably due to ignition of hydrogen (secondary to tissues coagulation) with the oxygen introduced during the procedure [60].

Complications of ureteroscopic incision

URS incisions can be used to treat a variety of upper tract obstructive processes, including ureteral and UPJ stenosis or calyceal diverticulum.

Ureteroscopic incision can lead to nonspecific as well as specific complications related to stenosis incision. Regarding specific complications, the most important one is bleeding secondary to incision, by injuring crossing vessels of the UPJ. The management of these complications includes various measures from watchful waiting associated with hemodynamic balancing to selective arterial embolization, or, in extreme cases, open surgery including nephrectomy. Various diagnostic methods such as endoluminal sonography and CT allow better detection of crossing vessels, thus leading to a considerable decrease of this complication [61]. Moreover, these methods, along with selective embolization, significantly reduce the number of cases requiring nephrectomy [62].

Measures to prevent complications

Patient selection and appropriate procedure planning are crucial for a successful intervention.

In order to prevent traumatic lesions of the ureter, a refined surgical technique is necessary for every operative step [11]. There is an obvious correlation between the complication rate and the endoscopic equipment and surgical skills. The routine use of a safety guidewire adjacent to the ureteroscope during upper tract endoscopy is considered essential in order to avoid or to solve the complications. However, some authors consider that the presence of a safety guidewire adjacent to the endoscope may prevent its passage. They claim that technologic advances in ureteroscope design and use of the holmium laser lithotripter minimize ureteral trauma and obviate the need for routine use of a safety guidewire during URS [63].

Appropriate equipment and accessory instruments are mandatory for a safe procedure. Any URS procedure must be performed under fluoroscopic guidance. While introducing the ureteroscope, any forced maneuver must be avoided. Excellent visibility should be maintained throughout the intervention.

If it is not possible to completely fragment the calculi or vision is reduced due to bleeding, the procedure should be stopped a ureteral stent placed, followed by a second-look URS. This approach is preferable to continuing with the initial intervention, which carries an increased risk of ureteral lesion.

Iatrogenic lesions are more common during the early phase of the learning curve, and consequently, the risk of serious complications is much higher for the inexperienced endoscopists. Nevertheless, with greater experience, more difficult cases will be approached, thus maintaining the probability of complications at a certain level.

Carefully performed URS is a superb tool for both diagnostic and therapeutic purposes and has a low rate of complications. The majority of these events can be corrected by conservative management.

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CHAPTER 48

Ureteroscopy into the Future: Robotic Ureteroscopy

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Introduction

The use of retrograde flexible ureteroscopy is routine for a variety of diagnostic and therapeutic applications involving the upper urinary tract. This has been the result of advances in flexible ureteroscope technology, holmium:YAG laser lithotripsy, and ureteroscope accessories such as irrigation systems, wires, baskets, graspers, forceps, and access sheaths. Despite major technologic developments that include better control of deflection, improved optics and working channel diameter, increased durability despite miniaturization, flexible ureteroscopy in its current form has limitations. These include lack of stability and fixity of the scope tip, fragility, poor ergonomics, need for an assistant, limited range of motion within the collecting system, and radiation exposure due to the proximity of the surgeon and assistant to the operating table and C-arm.

Computerized catheter control systems

Computerized catheter control systems (CCSs) are currently being developed and refined, primarily for cardiac applications. This development is driven by the need for accurate positioning and manipulation of a catheter tip in the three-dimensional (3D) cardiovascular space. Such systems employ either remote navigation in a magnetic field or a computer-controlled electromechanical flexible robotic system [1–3].

Endovascular procedures such as cardiac electrophysiologic ablations are technically complex, requiring a high-degree of precision and reproducibility. Accurate control of fine movements and sustained stability of an ablation catheter or endoscope tip is usually suboptimal using simple manual control when performing complex procedures. Manual control of catheters and flexible endoscopes faces several challenges:

- Most existing technologies are best suited for movement and navigation within relatively straight tubular structures;
- Animate organs, however, are comprised of complex 3D tissue spaces, the successful negotiation of which requires complex movements of catheters and scopes;
- Existing manual control mechanisms are relatively crude and are not designed for sustained stable positioning of the tip of a catheter or flexible endoscope;
- Using manual control to navigate within complex 3D tissue spaces requires considerable experience and a combination of complicated maneuvers, including insertion, rotation, and articulation, which is somewhat arbitrary and not always precisely reproducible;
- The long duration of many procedures exposes the physician to more X-ray radiation and nonergonomic strain than is desirable.

These challenges present the need for a computerized robotic platform that allows precise, fully controllable, complex maneuvers of a variety of flexible endoscopes and steerable catheters inside hollow organs, tissue

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spaces, and body cavities. Such a system should allow accurate surgical manipulation within these small spaces, thus transferring the maneuverability advantages of a rigid robotic system into the endoluminal environment.

While almost all ongoing research and development in this arena centers around cardiac electrophysiologic and endovascular applications, there is reason to believe that these systems can be adapted for use in almost all specialties that require advanced diagnostic or therapeutic flexible endoscopy.

To improve catheter manipulation during a cardiac electrophysiologic procedure, new tools based on robotic manipulation and navigation of cardiac catheters are being developed. One such system is a novel magnetic navigation system, Niobe (Stereotaxis, St Louis, MO, USA), which allows remote computer-controlled navigation of a magnetic catheter tip [1, 2]. The system utilizes two computer-controlled magnets located on opposite sides of the patient, which create a magnetic field. A small magnet in the catheter tip causes the movement of the catheter to be fully controlled within the external magnetic field. The movement of the catheter is motorized, allowing remote navigation. This system has reportedly been used for a remote cardiac ablation procedure, where the physician located in Boston treated a patient located in Milan, in real time [4]. Another CCS, Sensei™, that relies on computerized electromechanical manipulations has been introduced by Hansen Medical System (Mountain View, CA, USA). This CCS consists of a workstation console, an electronics rack, a steerable catheter system, and a remote catheter manipulator that is attached to the operating table with a pivot clamp. The workstation console has a joystick-like input device that allows precise control of the steerable catheter system, as well as three liquid crystal display (LCD) monitors that can provide information to the operator, such as from a C-arm, an endoscope camera, patient physiologic parameters, as well as an in-built mechanism to show the exact position of the catheter tip in 3D space.

Our hypothesis is that such a computerized CCS could potentially obviate some of the limitations of manual flexible ureteroscopy by providing a stable, readily maneuverable, and ergonomically superior platform. To test this, we used modified software and catheter configuration from the original system designed for cardiac applications [3] to determine the technical feasibility of robotic retrograde flexible ureterorenoscopy, initially in the acute porcine model [4, 5] and then in humans [6, 7].

Laboratory experience

In July 2007, the first animal experiments in ureteroscopy with the modified robotic CCS, Sensei™, were performed. The procedure was performed bilaterally in five acute female swine (27–51 kg) after approval from the Institutional Animal Care and Use Committee.

The equipment

The robotic catheter control system (Figure 48.1) is comprised of the following components surgeon console including the three LCD displays and master input device (MID); electronics rack; remote catheter manipulator (RCM), and steerable catheter system.

Surgeon console (operator workstation)

The surgeon console (Figure 48.2) consists of the MID, three display monitors, one touch screen, an electronics control panel, and a user interface pendant. The MID is a 3D joystick that the surgeon uses to remotely manipulate the catheter tip. The display monitors allow simultaneous visualization of the endoscopic and realtime fluoroscopic views. Facility also exists to incorporate and synchronize other imaging modalities, such as computed tomography (CT) scan or realtime ultrasonography. The surgical console also includes an electronics control panel which communicates with the electronics rack, controls the MID, and contains the workstation fault detection and mitigation hardware and software.

Steerable catheter system

The steerable catheter system (Figure 48.3) contains an outer catheter sheath (14/12F) and an inner catheter guide (12/10F). Movement of the MID intuitively controls the tip of the catheter guide. The ureteroscope (which was inserted into the inner catheter guide) used in our initial animal study was a custom-built passive fiberscope that incorporated two fiberoptic light bundles and a 6000 pixel optical bundle providing a 70° field of view. It also had a 3.4F central working channel for introducing accessories and providing outflow for the irrigant. Consequent to this animal study, the outer diameter of the ureterorenoscope was reduced from 8.5F to 7.0F to increase the space between the scope and guide, and provide an adequate channel for pressurized irrigation. The catheter guide also has a channel for injection and efflux of irrigant and/or contrast. The ureteroscope is introduced through the catheter guide and is manipulated by movements of the guide, which are controlled by the MID.

Remote catheter manipulator

The RCM (Figure 48.4) is the arm that fixes to the operating table using a simple clamp. The steerable catheter outer sheath and inner guide are mounted on the RCM. The RCM incorporates a single set-up joint for optimal positioning.

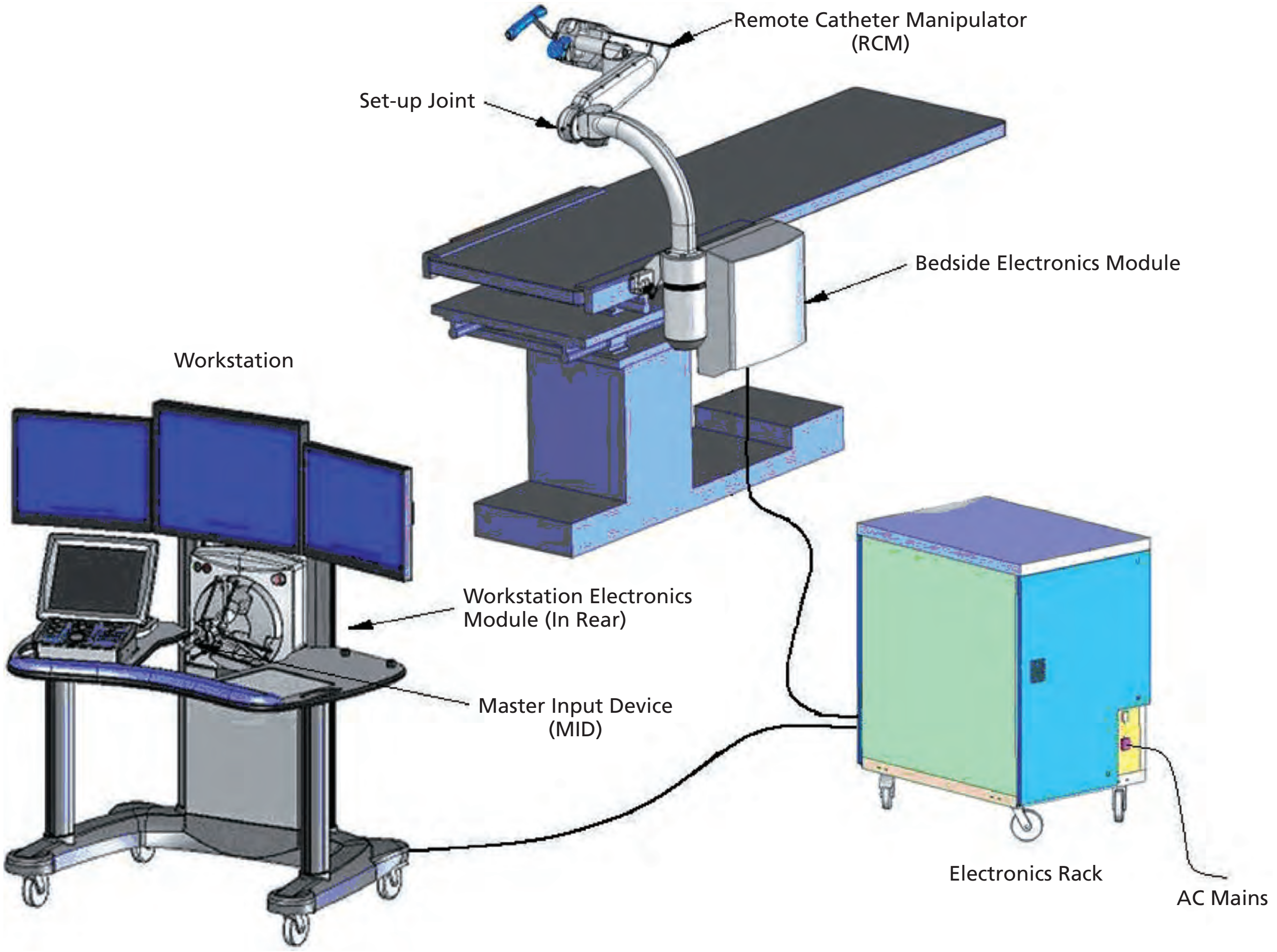
Remote Catheter Manipulator (RCM)
Set-up Joint
Bedside Electronics Module
Workstation
Workstation Electronics Module (In Rear)
Master Input Device (MID)
Electronics Rack
AC Mains

Figure 48.1 Components of the robotic catheter control system (Sensei™) comprising a surgeon console (workstation), an electronics rack, and a remote catheter manipulator on which the steerable catheter is mounted.

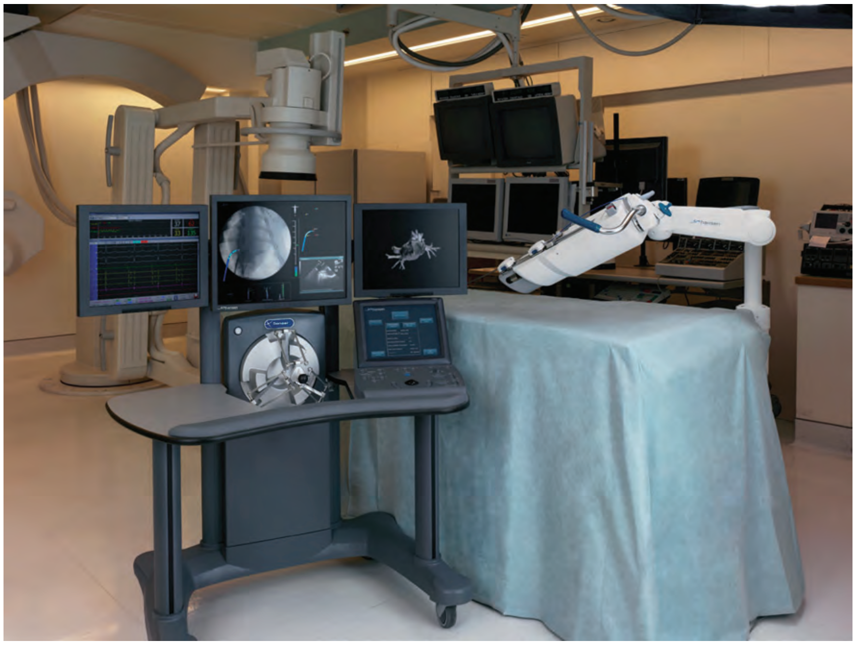

Figure 48.2 Operator workstation (surgeon console) showing three LCD screens, one touch screen, a control panel, and a joystick-like master input device (reproduced from Aron *et al*. [4] with permission).

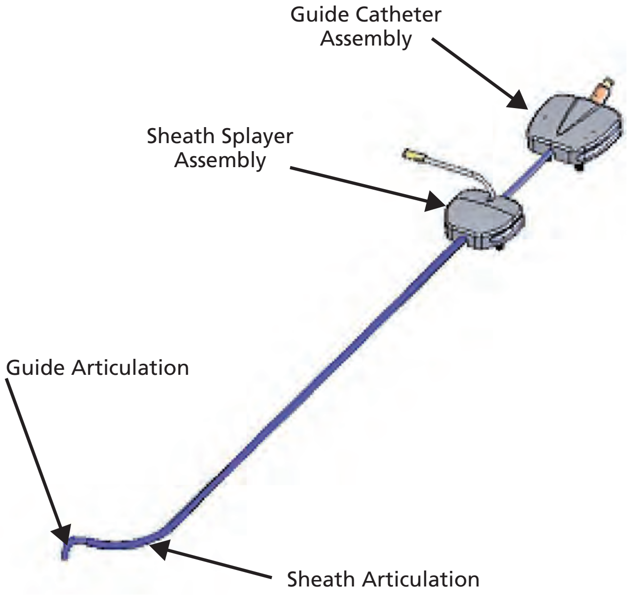

Figure 48.3 Steerable catheter control system comprising an outer sheath and an inner guide. The movements of the outer sheath and inner guide are independently controllable. The flexible endoscope fits into the inner guide and can be fixed therein, allowing it to be controlled by movements of the guide via the master input device.

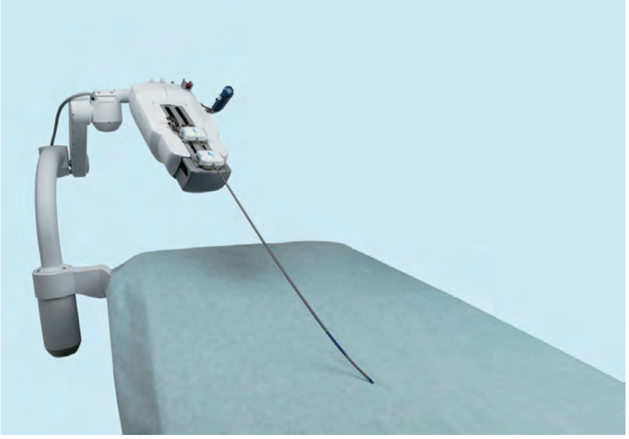

Figure 48.4 Remote catheter manipulator. The remote catheter manipulator (RCM) is fixed to the operating table using a simple clamp. The steerable catheter system mounts on the RCM (reproduced from Aron *et al*. [4] with permission).

Electronics rack

This contains all the hardware, including the computers, power supplies, and video distribution units.

Operative technique

Under general anesthesia, a 0.035-inch glidewire (Microvasive, Natick, MA, USA) was introduced cystoscopically into the ureteral orifice of the pig and positioned in the renal collecting system under fluoroscopic guidance. The outer catheter sheath and inner guide were inserted manually over the glidewire using an obturator. The obturator was removed and the ureteroscope introduced into the renal pelvis through the lumen of the inner guide. The catheter sheath, catheter guide, and ureteroscope were then mounted on the RCM (Figure 48.5). The RCM was draped with impervious plastic drapes to prevent fluid leakage onto the electronic components. Contrast was injected through the working channel to delineate pelvicalyceal anatomy. Each calyx was accessed ureteroscopically by remote manipulation via the MID. The robotic system software has two modes in which the catheter guide can be manipulated: fluoroscopic mode and endoscopic mode, that can be viewed simultaneously (Figure 48.6) or readily interchanged by pressing a button on the console. In addition, it is possible to determine the location and orientation of the scope tip in the collecting system by looking at the colored and shaded catheter animation on the LCD display (Figure 48.6). In two animals (four kidneys), three to five human stones from our stone collection, each approximately 4 mm in size, were introduced into the renal collecting system through the outer sheath. A holmium laser fiber was introduced into the working channel by the bedside assistant. Fragmentation was performed remotely using a 365–200 μm holmium:YAG laser fiber (Stonelight, Mountainview, CA, USA) set at 10 W (1.0 J, 10 Hz). In one animal (two kidneys), one papilla from each calyceal group (total six papillae) was laser ablated. An autopsy was performed

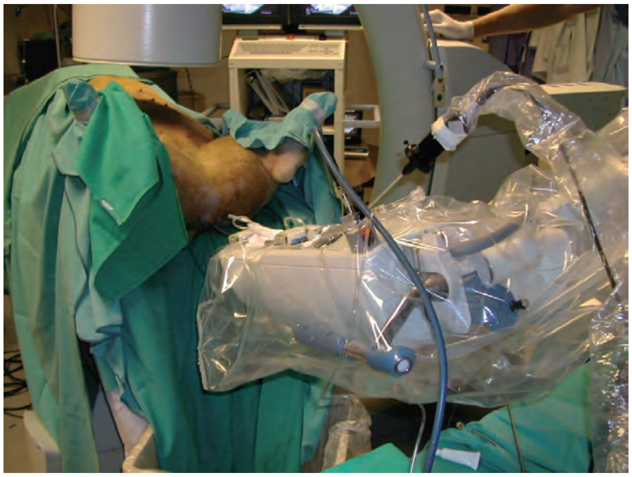

Figure 48.5 Acute porcine study with the steerable catheter and guide assembly mounted on the remote catheter manipulator. The custom-built ureteroscope was inserted through the inner guide. An endoscope camera was attached to the external end of the ureteroscope. The movements of the outer sheath and inner guide (and hence the ureteroscope) were controlled by movements of the joystick-like master input device on the surgeon console.

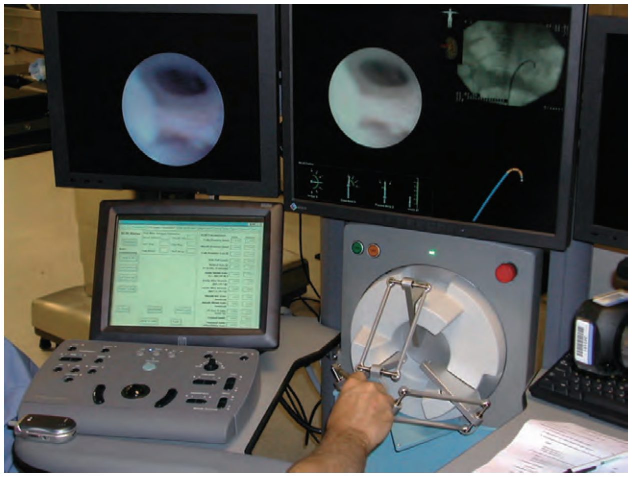

Figure 48.6 Porcine robotic ureterorenoscopy in progress. Endoscopic and fluoroscopic views can be seen simultaneously on the same or adjacent screens on the workstation. The computerized system also simultaneously displays the orientation of the catheter and location of the catheter tip in 3D space in the form of a realtime animation (arrow, blue – outer sheath, orange – inner guide)

at euthanasia and the kidney with entire length of ureter was harvested and submitted for histologic evaluation.

Specific parameters utilized to evaluate feasibility, safety, and performance of remote robotic ureterorenoscopic manipulations included the following:

- Need for ureteral dilation to accommodate the 14F outer sheath;
- Ability and time taken to access each minor calyx;
- Reproducibility of access into each minor calyx evaluated by success in re-entering each minor calyx three times;
- Ability to fragment intrarenal calculi and laser-ablate renal papillae;
- Stability of the system evaluated by the ability to "park" the ureteroscope tip at a desired location for a continuous 3-minperiod with the object in constant and optimal view;
- Reproducibility of the autoretract mechanism evaluated by being able to retract the scope tip to the original position;
- Integrity of the collecting system on retrograde pyelography;
- Evidence of ureteral and pelvicalyceal injury on gross and microscopic examination.

To objectively evaluate performance of the system as regards scope tip stability, reproducibility, and autoretract function, the surgeon completed a visual analog score (VAS) at the end of each procedure. The VAS was rated on a scale of 1 to 10, with 1 being the worst possible and 10 being the best possible performance.

Results

Balloon dilation of the intramural ureter was required in two of 10 porcine kidneys (20%) to accommodate the outer sheath of the robotic catheter system. Of the 85 calyces in the 10 kidneys, 83 (98%) could be adequately inspected with the flexible robotic system. Two lower pole minor calyces, one in each kidney of animal number 5 (weight 32 kg), could not be entered due to their small ostial size; however, a 3F basket could be passed into both these calyces under direct endoscopic vision. The time required to inspect the entire collecting system (mean 4.6 min) ranged from 15 min to 49 s, decreasing with experience from animal 1 through animal 5 (kidney 1 through kidney 10). All calculi could be fragmented with a laser fiber to a size smaller than the apparent diameter of the laser fiber in the four kidneys inserted with calculi. On the VAS, the stability of the system was rated at 10/10, reproducibility of access into each calyx at 10/10, and reproducibility of the autoretract mechanism at 8/10. Inaccuracies in the ability of the autoretract mechanism to return to the original vantage point were attributed to the movement of the UPJ with respiration. On retrograde pyelography, the collecting system was intact in nine kidneys (90%), and a perforation was noted at the ureteropelvic junction in one kidney (10%). This perforation occurred at the end of instrumentation due to surgeon error while retracting the robotic catheter in the flexed position. At autopsy, significant extravasation of irrigant was found in the retroperitoneum and peritoneal cavity in all five animals. Subsequently, the size of the prototype ureterorenoscope was reduced to 7.0F, thereby using the space between the ureteroscope and the guide catheter for infusion, and using the working channel space for efflux. Following this modification, ureterorenoscopy was performed in an additional animal and no retroperitoneal extravasation of irrigant at autopsy was observed. Furthermore, in the same animal, the measured volume of outflow (irrigant + urine) was slightly higher than the volume of inflow, thereby indicating adequacy of irrigant drainage.

Clinical experience

Based on lessons learned from the preclinical study and improvements made in the system, the first clinical study of flexible robotic ureterorenoscopy was performed after IRB approval. Robotic flexible ureterorenoscopic manipulations were performed in 18 patients with renal calculi using the modified Sensei™ system [6, 7]. Patients with solitary unilateral renal calculi measuring from 5 to 15 mm in size were included. Exclusion criteria were coexisting ureteral calculi or obstruction, uncontrolled infection, renal insufficiency, or solitary kidney status. Mean stone size was 11.9 mm. All patients were prestented for approximately 2 weeks. The robotic catheter system was introduced manually into the renal collecting system under fluoroscopic guidance over a guidewire. All intrarenal maneuvers, including stone relocation and fragmentation into 1–2-mm particles, were performed remotely by the surgeon seated at the robotic console (Figure 48.7). All procedures were technically successful, and all calculi were fragmented to the surgeon's satisfaction, without need for conversion to manual ureteroscopy. Mean operative time was 91 min, including a robot docking time of 7 min. Stone localization time was 9 min. The mean visual analog scale rating (from 1, worst, to 10, best) for ease of stone localization was 8.3, ease of maneuverability was 8.5, and ease of fragmentation was 9.2.

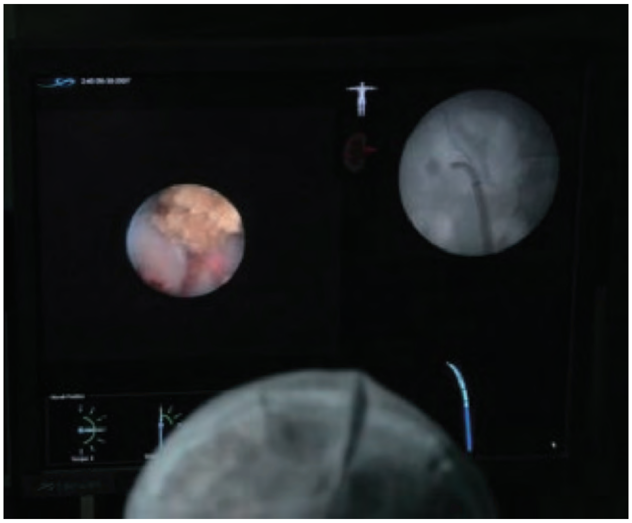

Figure 48.7 Clinical robotic ureteroscopy in progress. A calculus in the right kidney was located and fragmented with a holmium laser by the surgeon comfortably seated at the robotic workstation far from the radiation source

Complete fragment clearance was achieved in 56% of patients at 2 months, based on CT examination (Figure 48.8), and in 89% of patients at 3 months, based on intravenous urographic examination. One patient required secondary ureteroscopy for a residual stone.

Complications included pyelonephritis in two patients, pyrexia in one patient, and temporary positional limb paresis in one patient. There was negligible fluid absorption, based on calculated inflow and egress and on ethanol fluid absorption testing.

Future directions

The results of the initial porcine experiments and clinical trial are encouraging, although considerable refine-

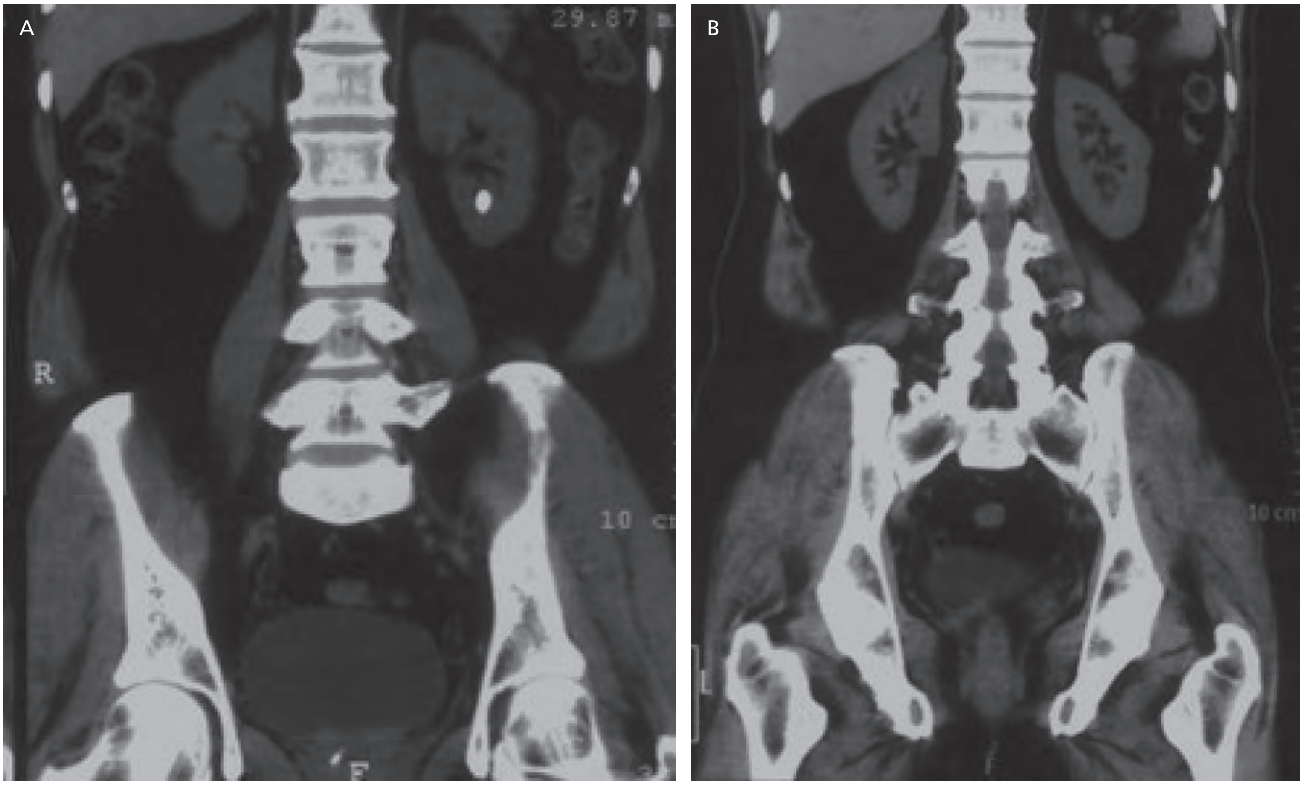

Figure 48.8 Clinical robotic ureteroscopy (URS). (A) Left inferior calyceal calculus prior to robotic URS and laser lithotripsy and(B) complete clearance 2 months after robotic laser lithotripsy

ments are still necessary. The system used for these experiments was not specifically designed for endourologic applications. This needs to be addressed for this to become a clinical reality. Whether or not industry will invest in this is dependent largely on market forces, and not so much on technologic limitations.

The ideal diameter of the outer sheath and consequently the other components is a matter of much debate. Remote robotic control of irrigation flow rate, introduction of wires, baskets, graspers, and laser fibers, as well as injection of iodinated contrast can potentially be incorporated into the system. Further refinements in robotic technology have the potential to provide additional benefits, such as automated movements and realtime surgical navigation utilizing realtime as well as archived imaging studies. Potential advantages of robotic ureteroscopy include precise control of the scope as well as enhanced stability, superior ergonomics, and decreased radiation exposure. Cost issues are important but undetermined at this time. The cost of ownership of the system for endourologic use is not known at this time since the system is not commercially available at this point. Nevertheless, it appears likely that the role of flexible catheter-based robotics in urology and other specialties is poised to expand for various intraluminal, transluminal, and laparoscopic applications. Further studies are necessary to determine the future role of emerging flexible robotic technology in surgical endoscopy.

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SECTION 4

Shock-Wave Lithotripsy

CHAPTER 49

Physics of Shock-Wave Lithotripsy

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Introduction

Shock-wave lithotripsy (SWL) was introduced in the 1980s for the treatment of urinary stones and earned near-instantaneous acceptance as a first-line treatment option [1]. At that time, SWL revolutionized treatment in nephrolithiasis worldwide and within one decade it was reported that more than 85% of patients in Europe and the USA were treated with lithotripsy [2, 3]. Since then, the use of SWL has been in decline and it has been estimated that around 70% of kidney stones were treated using SWL in 2002 [4] but less than 50% in 2005 [5]. Over the years lithotripsy has undergone several waves of technologic advance, but with little change in the fundamentals of shock-wave generation and delivery. That is, lithotripters have changed in form and mode of operation from a user perspective, and in certain respects the changes have been dramatic, but the lithotripter pressure pulse is still essentially the same. Lithotripters produce a signature waveform, an acoustic shock wave. This pressure pulse, or shock wave, is responsible for breaking stones. However, it is also responsible for collateral tissue damage that in some cases can be significant [6–11].

Lithotripters produce a powerful acoustic field that results in two mechanical forces on stones and tissue: (1) direct stress associated with the high amplitude shock wave; and (2) stresses and microjets associated with the growth and violent collapse of cavitation bubbles. Recent research has made significant advances in determining the mechanisms of shock-wave action, but the story is by no means complete. What fuels this effort is the realization that a totally safe, yet effective lithotripter has yet to be developed. For example, one trend in the evolution of SWL has been the development of lithotripters that produce very high amplitude and tightly focused shock waves, motivated by the desire to deliver more energy directly onto the stone. However, clinical data suggest that the use of tightly focused shock waves results in increased adverse effects and higher retreatment rates [4, 12–16], and basic research suggests that many shock waves miss the stone [17] and those that do interact with the stone do not result in effective stone fragmentation [18, 19]. In the past few years, manufacturers have started to widen the focal zone of their lithotripters, a move that takes advantage of new findings on the mechanisms of stone breakage with the potential to improve performance (see Focal zone of the lithotripter, below).

A major objective within the lithotripsy community is to find ways to make SWL safer and more efficacious. The perfect lithotripter may not exist, so urologists are left to determine how best to use the machines at hand. One step toward improving outcomes in SWL is to have a better understanding of how current machines work.

This chapter introduces the basic physical concepts that underlie the mechanisms of shock wave action in SWL. Our aim is to give the background necessary to appreciate how the design features of a lithotripter can affect its function. We also present a synopsis of current theories of shock-wave action in stone breakage and tissue damage and summarize recent developments in lithotripter technology.

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Characteristics of a lithotripter shock wave

A typical shock wave measured at the focus of a lithotripter is shown in Figure 49.1A. The wave is a short pulse of about 5 µs duration [1 microsecond (µs) = 1 millionth of a second]. In this example the wave begins with a near instantaneous jump to a peak positive pressure of about 40 MPa [1 megaPascal (MPa) is about 10 atmospheres of pressure]. This fast transition in the waveform is referred to as a "shock." The transition is faster than can be measured and is less than 5 ns in duration [1 nanosecond (ns) is 1 billionth of a second]. The pressure then falls to zero about 1 µs later. There is then a region of negative pressure that lasts around 3 µs and has a peak negative pressure of around –10 MPa. The amplitude of the negative pressure is always much less than the peak positive pressure and the negative phase of the waveform generally does not have a shock in it, i.e. there is no abrupt transition. The entire 5-µs pulse is generally referred to as a shock wave, shock pulse or pressure pulse; however, technically it is only the sharp leading transition that is formally a shock.

Figure 49.1B shows the amplitude spectrum of the shock pulse, i.e. the different frequency components in the pulse. It can be seen that a lithotripter shock wave does not have a dominant frequency or tone, but rather its energy is spread over a very large frequency range; this is a characteristic feature of a short pulse. It can be seen that most of the energy in the shock wave is between 100 kHz and 1 MHz. This means the analogy of an opera singer shattering a crystal glass by singing at the right pitch (single frequency) is not appropriate for lithotripsy due to the multitude of frequencies present.

The waveform shown in Figure 49.1A was measured in an electrohydraulic lithotripter (a description of different types of shock wave generators is given below). Most lithotripters produce a similar shaped shock wave and in Figure 49.2A waveforms measured in an electrohydraulic lithotripter and an electromagnetic lithotripter at a high power setting are compared. It can be seen that both waveforms have a form that is common to all shock waves used in lithotripsy: a high amplitude compressive phase of extremely rapid transition (<1 ns) and short duration (~1 µs) followed by a trailing tensile phase (~3 µs). In this case the amplitude of the peak positive pressure of the electromagnetic lithotripter is 2.5 times that of the electrohydraulic lithotripter. In general, pressure amplitudes are machine and setting specific, and the peak positive pressure can vary from 20 to 110 MPa and the negative pressure from –5 to –15 MPa. For example, Figure 49.2B shows waveforms measured at lower power settings of both machines, and again the waveforms are similar but the peak amplitudes differ by less than 50%. Further, the spatial dependence of the pressure field is also machine and setting specific and this will be discussed below.

Acoustics primer for shock-wave lithotripsy

What is an acoustic wave?

An acoustic wave, or sound wave, is created whenever an object moves within a fluid (a fluid can be either a gas or liquid). In Figure 49.3 it is shown that as an object moves, it locally compresses the fluid that surrounds it, i.e. the molecules are forced closer together. The region of compressed molecules in turn pushes against the molecules next to it. This relieves the compression in the first region but leads to a new compressed region. The molecules in the second region then start to compress the next

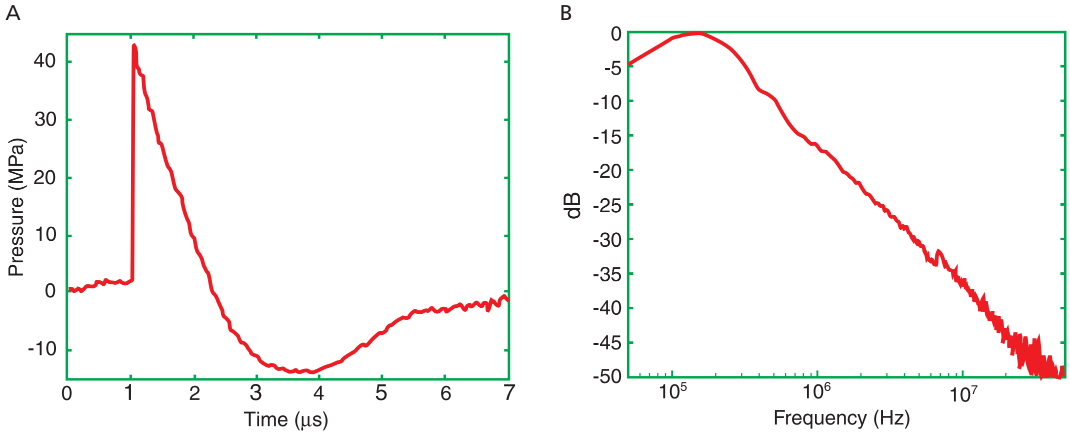

Figure 49.1 (A) A pressure waveform measured at the focus of an electrohydraulic lithotripter (Dornier HM3). (B) Fourier transform of the waveform in A showing how the energy is distributed as a function of frequency. Both axes are shown on a log scale. The peak of the amplitude response is around 300 kHz, which corresponds to a duration of 4 µs. It can be seen that this persists until frequencies of about 20 MHz.

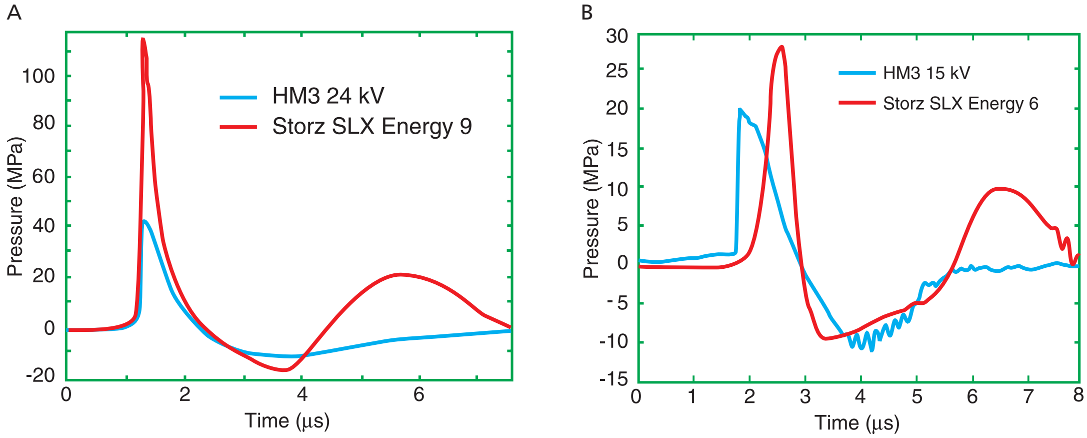

Figure 49.2 (A) Focal waveforms measured in the Dornier HM3 at 24 kV and the Storz SLX at Energy level 9. (B) Comparison at lower settings: the amplitudes are about the same but the SLX waveform has not formed a shock.

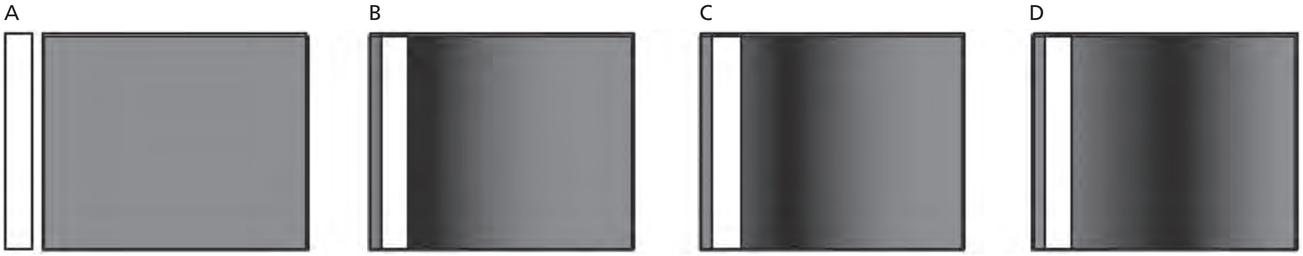

Figure 49.3 Molecular view point of a sound wave. (A) Medium is at rest. (B) A piston pushes all the molecules out of the left side, resulting in a localized region of compression at the face of the piston (dark region). (C) The neighboring molecules are compressed and the compression region moves away from the piston. (D) The wave continues to move away from the piston while the molecules at the piston return to their initial condition.

adjacent region and so on; it is thus that a "wave" of compression travels through the fluid. This is an "acoustic wave" and the speed of wave propagation (called the sound speed) is a material property of the medium; for air it is about 340 m/s, and in water and most soft tissues in the body it is about 1500 m/s. Note that individual molecules do not travel with the acoustic wave, rather they just jostle their adjacent neighbors. Therefore, for an acoustic wave to propagate, there must be a medium present that can support the vibrations. This is an important physical difference between classical waves (e.g. acoustic waves, seismic waves, water waves) and electromagnetic waves (e.g. light, radio waves, X-rays). For electromagnetic waves energy is carried by photons, which may be thought of as particles, which physically travel through space; thus, a medium is not needed for the signal to be transferred. Therefore, light can travel through a vacuum but sound cannot.

Sound waves have compressive and tensile phases

The explanation above describes the compressive phase of a sound wave, i.e. where the molecules are compressed. For the case where the object moves away from the fluid, there is a resulting rarefaction of the molecules, i.e. the moving object leaves a partial vacuum. In this case, the neighboring molecules will move to fill the void, leaving a new region of rarefraction. This continues one region to the next and the rarefractional disturbance propagates through the medium as a tensile acoustic wave. In most cases a tensile wave propagates just like a compressive wave and with the same sound speed.

Typical acoustic sources, such as audio speakers, vibrate backwards and forwards. This produces alternating compression and rarefraction waves that are referred to as the compressive phase and tensile phase of the acoustic wave. Often the waveform is sinusoidal in nature. Note, however, that the majority of acoustic waves, including the acoustic pulses generated in lithotripsy, are not sinusoidal in form. For small-amplitude waves (linear acoustics) every point of the waveform moves at the same speed, the sound speed c_0. This is a material property and for water and tissue it is about 1500 m/s. It will be shown later that for large amplitude (nonlinear) acoustic waves, such as shock waves, the sound speed is slightly changed by the presence of the wave.

The waveform shown in Figure 49.1 displays the pressure pulse as a function of time at a given point in space. This is typically how acoustic waves are measured, e.g. a microphone will record how pressure varies in time at one point in space. However, acoustic waves also vary in space and it is often useful to think of the wave in terms of its spatial extent. The relationship between the temporal separation of points on an acoustic wave (Δt) and the spatial separation of the points (Δx) is given by:

$$\Delta x = \Delta t\, c_0 \qquad \text{(Eq 49.1)}$$

Recall that in water or tissue the c_0 is 1500 m/s (1.5 mm/µs) and therefore, for the shock wave shown in Figure 49.1, the positive part of the wave (a portion 1 µs long in time) will have a spatial extent in water of 1.5 mm. For a sinusoidal wave, the spatial extent of one cycle of the wave is called the *wavelength*.

Sound waves are not just pressure waves

When a sound wave propagates, it affects the density, pressure, and particle velocity of the fluid particles. The impact on the density occurs because as molecules are compressed together, the local density (ρ) will increase and in regions of rarefraction the density will decrease. For an acoustic wave it is convenient to write the total density as:

$$\rho = \rho_0 + \rho_a \qquad \text{(Eq 49.2)}$$

where ρ_0 is the ambient density of the medium (in the absence of sound) and ρ_a is the variation in the density due to the acoustic wave.

The pressure in the fluid can similarly be written as the sum of two terms:

$$p = p_0 + p_a \qquad \text{(Eq 49.3)}$$

where p_0 is the ambient pressure (in the absence of sound) and p_a, the *acoustic pressure*, is the fluctuation due to the sound wave. For most fluids, acoustic pressure and density are directly related by an "equation of state" which takes the form:

$$p_a = \rho_a\, c_0^2 \qquad \text{(Eq 49.4)}$$

That is, where the wave is compressed the pressure will be positive and where the fluid is rarefied the pressure will be negative. Physically, pressure represents a force per unit area and has units of Pascals (Pa). One Pascal is quite a small pressure and atmospheric pressure at sea level is approximately 100 000 Pa. In biomedical ultrasound, acoustic pressure is normally measured in megaPascals (MPa).

By way of example, the amplitude of the pressure from a diagnostic ultrasound scanner is about 2 MPa at the focus. Typically, values for ρ_0 and c_0 in tissue are 1000 kg/m^3 and 1540 m/s, respectively, and so this corresponds to a relative density perturbation of $\rho_a/\rho_0 = 0.0009$. For lithotripsy, peak pressures can be upwards of 100 MPa, which results in $\rho_a/\rho_0 = 0.04$. Therefore, the density disturbances associated with acoustic waves in medical devices, even the very strong waves that are produced in lithotripsy, actually result in very weak (<5%) compression of the fluid.

Progressive waves and particle velocity

The case shown in Figure 49.3 where the compression wave moves in one direction is referred to as a *progressive wave*. In contrast, when there are sound waves traveling in different directions, this is referred to as a *compound wave*, which will not be considered here. For a progressive wave the molecules in the compressed region also have a small net velocity away from the source. The net velocity of the molecules in a region of space is referred to as the *particle velocit*y (u_a) and for a progressive acoustic wave it can be expressed as:

$$u_a = p_a / \rho_0\, c_0 \qquad \text{(Eq 49.5)}$$

Using the example of a 100-MPa shock wave, the instantaneous particle velocity at the peak is about 67 m/s. It will be shown below that the particle velocity is needed in order to determine the energy in an acoustic wave.

If the velocity is integrated in time, the displacement of tissue can be calculated. For the 100-MPa shock wave described above, the tissue will move about 30 µm during the 1 µs compressive phase and then slowly return to its original position during the tensile phase. It has also been suggested that the particle velocity within a biologic target may produce sufficient strain to damage the cells. Below it will be discussed how the deformation can also build up over many pulses and in certain cases may damage tissue.

Acoustic impedance

The density and sound speed of a material (Eq 49.4) determine its *specific acoustic impedance* ($Z_0 = \rho_0\, c_0$). This term is often shortened to *acoustic impedance* or just *impedance*. The impedance of tissue and water is about 1.5×10^6 kg/m^2/s. The units are often referred to as Rayls, after the eminent 19th century acoustician Lord Rayleigh, although the Rayl is not a standard SI unit.

Therefore, for a progressive acoustic wave, the pressure, density and particle velocity are not independent but are linearly related to each other:

$$p_a = u_a Z_0 = \rho_a c_0^2 \qquad \text{(Eq 49.6)}$$

where the coefficients are material properties. It follows that regions of high pressure are also compressed and have a high particle velocity (away from source), and regions of low pressure are rarefied and have a negative particle velocity (towards the source). As the acoustic wave travels, the fluctuations in density, pressure, and particle velocity all move together (i.e. "in phase"). Therefore, in a fluid with known material properties, if one property of an acoustic wave, such as the acoustic pressure, is measured, then Eq 49.5 can be used to determine the other acoustic properties.

Wave intensity or energy

A propagating acoustic wave carries energy. The amount of acoustic energy per unit area is called the *energy flux, energy density, energy flux density*, or the *pulse intensity integral*. An IEC standard, which describes how pressure measurements should be taken on a lithotripter to ensure accurate results and fair comparisons across devices, defines the energy per unit area the "pulse intensity integral (energy density)" (PII) [20]. It can be calculated from the following integral:

$$PII = \int p_a u_a dt \qquad \text{(Eq 49.7)}$$

where the integration is done over the duration of the pulse. This is the acoustic equivalent to the expression from physics "work equals force times distance," where acoustic pressure is the force per unit area and the time integral of the velocity gives the distance. The units for PII are joules per square meter (J/m^2). For a progressive wave it is known that the particle velocity is related to the acoustic pressure $u_a = p_a/Z_0$ and therefore:

$$PII = \int \frac{p_a^2}{Z_0} dt \qquad \text{(Eq 49.8)}$$

in which case the pressure of the wave needs to be measured to determine PII. Note that to calculate the integral, the entire pressure versus time waveform needs to be accurately measured so that the integration can be done.

To determine the energy in an acoustic wave, a specific area A has to be chosen and the energy that passes through that area can then be calculated as:

$$E = \iint PIIdA \qquad \text{(Eq 49.9)}$$

where the double integral indicates a surface integral over the area A. The units for energy are Joules (J). The energy E will depend on both the size of the area A and how the intensity varies across the area. The *focal acoustic pulse energy* is calculated using the area in the focal plane where the pressure is greater than half the maximum pressure (this is equivalent to the *focal zone*, see below). Various other conventions have been employed to calculate energy in SWL, e.g. the projected area of a stone or the area where the peak pressure is above 5 MPa [21].

Another acoustic property is the power per unit area or the *intensity* (*I*). Power is energy per unit time and so the intensity is the energy density divided by the time over which the integration was done (Eq 49.8), which is normally the pulse length (T_p):

$$I = \frac{PII}{T_p} \qquad \text{(Eq 49.10)}$$

Intensity has units of watts per square meter (W/m^2) but it is more common in biomedical ultrasound to use W/cm^2.

For a sinusoidal pressure wave the integral (Eq 49.8) can be calculated exactly and the intensity is:

$$I = \frac{\hat{p}^2}{2Z_0} \qquad \text{(Eq 49.11)}$$

where $\hat{p}$ is the peak pressure of the sinusoidal wave. If the impedance for water or tissue (Z_0 = 1.5 MRayls) is substituted, the relationship can be expressed as $\hat{p} = \sqrt{3I}$ where $\hat{p}$ is in atmospheres of pressure and *I* is in W/cm^2. For pulsed pressure waves, such as in lithotripsy, a simple expression does not exist for the intensity, as even small changes in the pulse shape can have a significant effect on the integration used to calculate *PII*.

Reflection and transmission of sound waves

When an acoustic wave encounters a medium with a different impedance, then part of the wave will continue to propagate into the new medium (the transmitted wave) and part of the wave will be reflected back into the original medium (the reflected wave). In the case of *normal incidence*, where the propagation direction of the shock wave is perpendicular to the surface, the amplitude of the transmitted and reflected waves depends only on the change in impedance between the two media, what is referred to as the *impedance mismatch*. In terms of acoustic pressure the transmission and reflection coefficients are:

$$R_p = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad \text{(Eq 49.12)}$$

$$T_p = \frac{2Z_2}{Z_2 + Z_1} \qquad \text{(Eq 49.13)}$$

There are a different set of coefficients for the intensity or energy, which are called the intensity transmission and reflection coefficients:

$$R_I = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2} = R_p^2 \qquad \text{(Eq 49.14)}$$

$$T_I = \frac{4Z_1Z_2}{(Z_2 + Z_1)^2} = 1 - R_I \qquad \text{(Eq 49.15)}$$

Figure 49.4 shows the intensity transmission coefficient for an acoustic wave going from water to another medium with different impedance. The typical values for tissue, kidney stones, bone, and air are indicated. It can be seen that the transmission from water to tissue is very efficient. The water–stone transmission is also relatively high, with 75–95% of the energy being transmitted into kidney stones. However, a water–air interface has an extremely small coefficient and less than 0.1% of the energy of an acoustic wave in water will pass into air, i.e. 99.9% is reflected. This is why shock-wave generators in lithotripsy are water filled, why immersion of the patient in water gives the most efficient coupling of shock waves to the body, and why in dry lithotripters great care must be taken to eliminate air pockets between the shock head and the body [22, 23]. This is also one reason why stones are not targeted for treatment through lung or segments of gas-filled bowel. Indeed, the best *acoustic window*, which allows the shock wave a pure tissue path to the kidney, is on the flank of the patient (delineated by the ribs, spine. and pelvic bone).

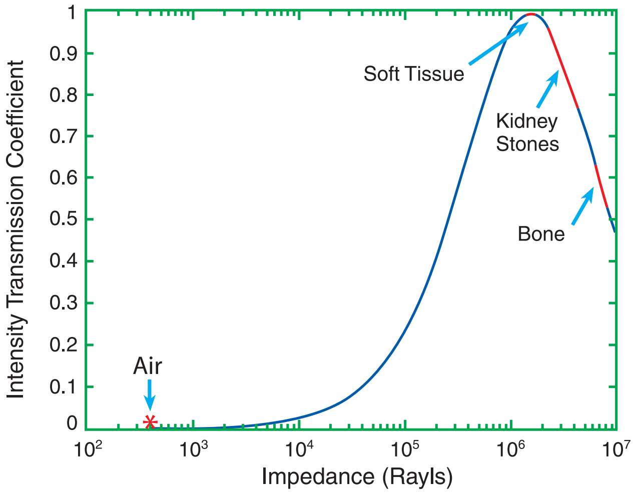

Figure 49.4 Intensity transmission coefficient (TI) from water ($Z = 1.5 \times 10^6$ Rayls) to a second medium, as a function of the impedance of the second medium. Typical values are indicated for soft tissue, kidney stones, bone, and air. The transmission to soft tissue is very efficient. Coupling to air is very poor.

Focusing and diffraction of sound

In lithotripsy, focusing of the shock waves is used to concentrate the acoustic energy on to the stone, while reducing the impact on the surrounding tissue as much as possible. Lithotripters achieve focusing by various means, including the use of reflectors, acoustic lenses, and spherically curved sources. Regardless of the method used, the physics that describes the focusing of the waves is similar for all these cases. An ideal focus would be the case where all energy is localized to an infinitesimally small region in space. However, the physics of wave propagation does not allow the energy to be focused to an arbitrarily small volume due to a process called *diffraction*. This means that even though the acoustic pressure may be greatest at one point in space, there is a finite region or volume of surrounding space that is also at high amplitude. This called the *focal zone*. For a theoretically optimal focusing arrangement, where sound can come in from all angles, diffraction puts a limit on the size of the focal zone of about one wavelength. For the realistic focusing arrangements used in lithotripsy, where the sound only comes from one direction, the focal zone can be from a few millimeters to tens of millimeters in size.

Focal zone

The *focal zone* of a lithotripter (equivalent terms include *focal region*, *hot spot*, *focal spot*, *focal volume*, *zone of high pressure*) of a lithotripter is normally ellipsoidal in shape with its longest dimension along the axis of the shock wave. To demonstrate this, Figure 49.5 shows the predicted peak pressure of the focal zone in an unmodified Dornier HM3 lithotripter [24]. The length and diameter

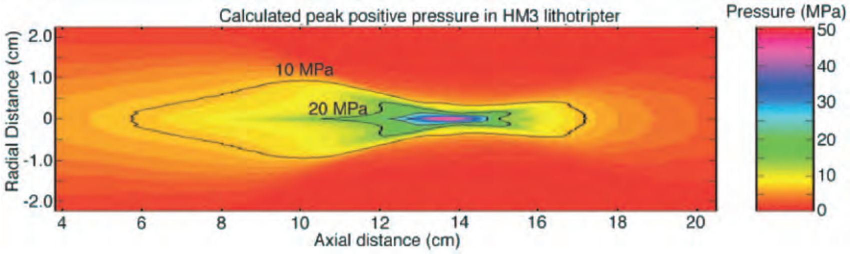

Figure 49.5 Calculated spatial distribution of the peak positive pressure for the Dornier HM3 lithotripter. The focal volume can be determined by determining the zone where the pressure is at least half the maximum pressure.

of the focal zone depends on the diameter of the source, the focal length of the source, and the frequency content of the waveform. The dimension of the focal zone is, thus, one characteristic of any given lithotripter that is determined by design features and, as will be discussed below, focal zones can vary greatly between lithotripters.

For a focused acoustic source that generates a sinusoidal waveform, such as an ultrasound transducer, there are analytical expressions for the size of the focal zone. The critical parameters are the wavelength of the sound wave (λ) and the half angle of the aperture:

$$\alpha = \arcsin(D/2F). \qquad \text{(Eq 49.16)}$$

where D is the diameter of the source and F the *focal length*. The formulae for the length (L_{FZ}) and the diameter (D_{FZ}) of the focal zone are:

$$L_{FZ} = \frac{0.6\lambda}{\sin^2(\alpha/2)} \qquad \text{(Eq 49.17)}$$

$$D_{FZ} = \frac{0.7\lambda}{\sin\alpha} \qquad \text{(Eq 49.18)}$$

Note that the focal length (F) is the distance from the mouth of the therapy head to the focus (where the stone should be placed). The focal length should not be confused with the length of the focal zone (L_{FZ}), which is the region around the focus where the pressure is high.

For a pulsed waveform, as is generated in lithotripsy, there are no explicit formulae for the size of the focal volume as the size depends on the waveform shape. However, the focal region of a lithotripter can be estimated using the formulae for the focal region of a sine wave. Figure 49.6A shows how the focal zone gets shorter and narrower as the diameter of the source aperture is increased. Figure 49.6B shows how the focal zone gets shorter and narrower as the focal length of the source (source–target distance) is decreased. Therefore, to make a small focal zone, a shock source with a large diameter aperture and short focal length would be desired. However, the size of the acoustic window in the flank and the need to be able to target stones deep in the body mean that for most lithotripters both the focal length and the diameter of the aperture are around 15 cm.

Nonlinear acoustics

When an acoustic wave has very large amplitude, e.g. a lithotripter shock wave, the speed of the wave is no longer constant but depends on the local compression of the fluid. For "weak" shock waves (recall even at the focus of the highest power lithotripter, the water is compressed by < 5%), the speed of propagation ("phase speed") of an acoustic wave is:

$$c_{phase} = c_0 + \beta p_a / \rho_o\, c_0 \qquad \text{(Eq 49.19)}$$

where β is the *coefficient of nonlinearity* of the fluid and is a material property of the medium. For water β is about 3.5 and for tissue it varies from about 4 to 9. Normally, tissue of more complex structure has a greater coefficient of nonlinearity. A reasonable value for healthy soft tissue is 5.

Nonlinearity arises because of two physical processes; first, in regions of high pressure the local sound speed is increased above the usual value, and second the molecules in regions of high pressure have a higher particle velocity and are convected in the direction of acoustic propagation. For sound traveling through tissue, it is the first process that dominates the nonlinearity.

The difference between a nonlinear wave and a linear wave is that for a nonlinear wave, different parts of the wave travel at different speeds, as described by Eq 49.19. Figure 49.7 shows what happens to a sinusoidal wave as it propagates with nonlinearity present. The waveform becomes distorted in shape. In the absence of absorption, the wave obtains an infinite slope and then folds over and becomes multivalued. Ocean waves fanning up the beach are such waves but this waveform is not physically realizable in acoustics, i.e. it is not possible to have more than one pressure at any one point in space.

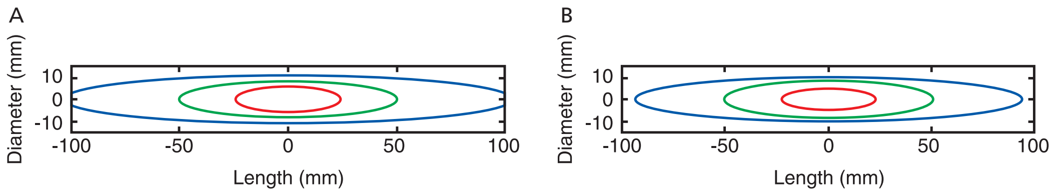

Figure 49.6 Predicted focal zone size as a function of the diameter of the source and the focal length of the source for a 500 kHz source. (A) Contours show size of the focal zone for a source that has a focal length of 14 cm and an aperture of 25 cm (red), 15 cm (green), and 10 cm (blue). The focal zone gets longer and wider as the aperture size decreases. (B) Contours show the size of the focal zone for a source with fixed aperture diameter (15 cm) and varying focal length: 8 cm (red), 14 cm (green), and 20 cm (blue). The focal zone gets broader and longer as the focal length increases. For reference the Dornier HM3 hemi-ellipsoidal reflector has a focal length of 13 cm and an aperture diameter of 15 cm.

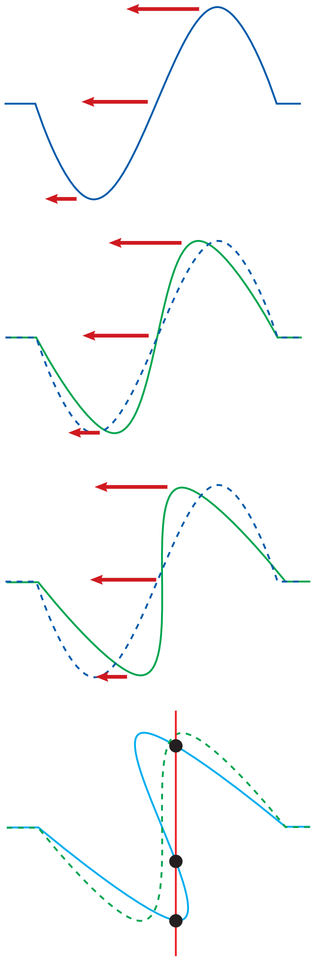

Figure 49.7 Nonlinear distortion of a sine wave based on Eq 49.19. (A) Initial waveform; the length of the arrows shows the local phase speed of different points on the waveform. The peak will move the fastest and the trough the slowest. (B) Waveform after a short amount of propagation (dashed line is waveform in A) showing how the shape has distorted. (C) Shock formation distance where the slope of the waveform first becomes infinite (dashed line is waveform in A). (D) Predicted multi-valued waveform; the vertical line indicates that there are three different pressures predicted at one point in time (dashed line is from C). This shape is nonphysical as absorption will prevent the wave from folding over.

Shock formation

The point at which the waveform first attains an infinite slope is called the *shock formation distance*. For a sinusoidal waveform this distance is:

$$\bar{x} = \frac{\rho_0 c_0^3}{\beta \hat{p} 2\pi f} \qquad \text{(Eq 49.20)}$$

Any acoustic wave can result in a shock wave if it can propagate for a long enough distance. However, for most sound waves encountered in everyday life, the shock formation distance is so long that the wave has been absorbed before it can form a shock.

Rise time

In acoustics, waveforms are prevented from folding over (or breaking) by the presence of acoustic loss mechanisms. All acoustic waves will leave behind a small fraction of their energy as they propagate through a fluid; this loss of energy is referred to as *absorption* and will be discussed in the next section. The absorption of sound is greater from waveforms with steep gradients. In the case of a shock wave where the slope tends towards infinity, the absorption will also tend towards infinity. The shock will, therefore, never attain an infinite slope, but instead a balance between nonlinear distortion and absorption will result in a shock front where the pressure jumps in a very short time. This time is referred to as the *rise time* of the shock or the Taylor shock thickness. For a shock wave in water the expression for the Taylor shock thickness is:

$$T_{rt} = \frac{5}{\Delta P}\,\text{ns}\cdot\text{MPa} \qquad \text{(Eq 49.21)}$$

where ΔP is the pressure jump in MPa and the rise time (in ns) is defined as the time to go from 10% to 90% of ΔP. From this expression it is found that a 1-MPa shock should have a rise time of 5 ns and a 10-MPa shock a rise time of 0.5 ns. As a shock becomes stronger, the rise time shortens. Using Eq 49.1, the corresponding spatial extent of the rise time of the 1- and 10-MPa shock waves is 7.5 µm and 0.75 µm, respectively.

Nonlinear acoustics phenomena are also important in other areas of biomedical ultrasound. In diagnostic ultrasound, nonlinear effects can create problems such as excess heating of tissue [25, 26], but can also be beneficial by enhancing image quality in tissue harmonic imaging [27–29]. Nonlinear effects are also important in high intensity focused ultrasound surgery (HIFU or FUS), where ultrasonic heating of tissue is exploited to destroy specific regions of tissue or to coagulate blood [30–33].

Absorption of sound by tissue

As mentioned above, when a sound wave passes through a medium, most of the energy remains in the sound wave but a small amount of it is absorbed by the medium. The amplitude of an acoustic wave will therefore slowly decay or *attenuate* as it propagates through a medium. The absorption in water is very low and, aside from controlling the rise time of the shock front, has little effect on lithotripter waveforms. The absorption in tissue, however, is about 1000 times larger than that in water and has a measurable effect on lithotripter

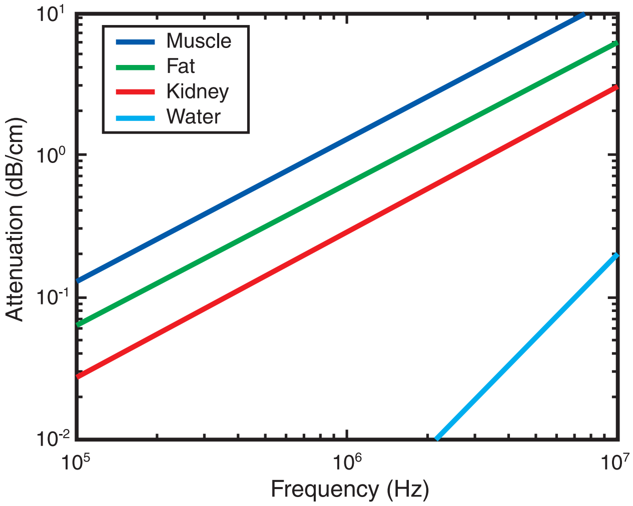

Figure 49.8 Attenuation of sound as a function of frequency for muscle, fat, and kidney tissue (listed in decreasing order of loss). Also shown is the attenuation in water, which is much less (1000 times at 1 MHz) than the attenuation of tissue.

shock waves as they pass through the body and into the kidney. Typical values for absorption in muscle, fat, and kidney are shown in Figure 49.8 as a function of frequency. It can be seen that the absorption increases (almost linearly) with frequency. This means that energy is removed more effectively from the higher frequencies of the sound wave. In lithotripsy waveforms, the high frequency components are associated with the shock front. The primary action of tissue absorption is to increase the rise time of the shock front, and this will also result in the peak amplitude being reduced. The main energy components of the wave (which are around 300 kHz) will not be significantly impacted by tissue attenuation, and therefore the basic shape of the pulse is not be affected by propagation through tissue and the peak negative pressure in particular is not sensitive to tissue absorption.

How shock waves are measured

Hydrophones

The main physical property of a lithotripter is the spatial and temporal distribution of its acoustic pressure field. The acoustic field is typically measured in water using a hydrophone, which converts pressure into an electrical signal. Lithotripters generate short (wide frequency band), high amplitude acoustic pulses, which are focused to a small volume in space. These physical parameters require that the hydrophone needs to be: (1) of a very wide bandwidth (60 kHz to in excess of 20 MHz); (2) robust enough to withstand the high pressures of the shock waves; and (3) possess a small active area (~0.5 mm). The first reliable measurements of lithotripsy shock waves were performed with a hydrophone made of polyvinyl difluoride (PVDF), a piezoelectric plastic [34]. PVDF has very wide bandwidth, is capable of measuring high amplitude acoustic pressures, and can be manufactured so that only a small region is active. Both membrane hydrophones and needle hydrophones have been used, however membrane hydrophones are considered to yield the best measurement of the shock wave [35]. One problem with PVDF is that its adhesion with water is not strong and the tensile phase of the lithotripsy pulse can result in cavitation at the surface of the PVDF. This is a significant limitation that has two main consequences. First, it limits the ability of the hydrophone to measure the tensile phase of the shock wave as once the bubble forms the negative pressure is relieved and the hydrophone registers a pressure close to zero. Second, when the cavitation bubbles collapse, they can irreversibly damage the hydrophone.

The fiberoptic probe hydrophone (FOPH) [36] is considered to be the state of the art for measuring lithotripsy shock waves, and is the recommended device in the IEC standard [20]. The FOPH consists of a laser that injects light into one end of an optical fiber; the other end of the fiber is placed in the lithotripter field. The FOPH measures the light that is reflected from the end of the fiber and exploits the fact that the amplitude of the reflection depends on the pressure in the fluid. Several features make the FOPH superior to the PVDF membrane. Similar to PVDF, the FOPH has a wide bandwidth and is capable of measuring very high pressure amplitudes. The diameter of the active area of the FOPH (100 µm) is smaller than most PVDF hydrophones (500 µm). Also, the FOPH is made of an optical fiber (silica) and the adhesion between water and silica is very high. This means that cavitation is much less likely to occur at the surface of the FOPH and therefore it can more accurately capture the tensile phase of the shock wave. This also means that the FOPH is less susceptible to damage from cavitation. The main drawback with the FOPH is that the signal it generates is weak and therefore it is not good for measuring low pressures (~2 MPa and less).

Measuring shock waves in the body

All published measures of dimensions of the focal zone come from *in vitro* experiments and there have been few attempts to collect any shock-wave pressure data in animals. Both the high attenuation and inhomogeneous nature of tissue will affect shock waves as they propagate through the body. Figure 49.9 shows representative pressure waveforms for a Dornier HM3 measured in water and for a PVDF membrane hydrophone implanted in a pig [37]. The *in vivo* waveform is very similar in

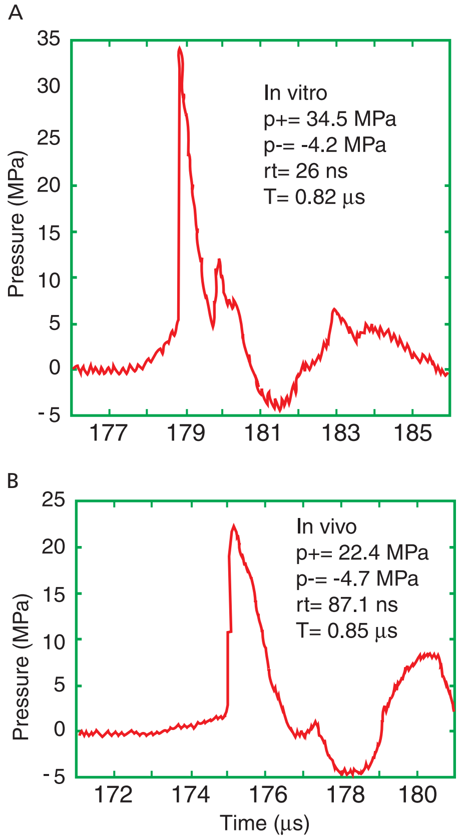

Figure 49.9 (A) Waveform measured in water with a miniature polyvinyl difluoride (PVDF) hydrophone in a Dornier HM3 at 18 kV. (B) Waveform measured *in vivo* in a pig for the same settings. The peak amplitude *in vivo* was about 30% less than that in water, and the rise time *in vivo* (78 ns) was much longer than that measured in water (26 ns).

basic shape to the *in vitro* waveform. The main difference is that the *in vivo* waveform has a 30% decrease in peak positive pressure and a greatly increased shock rise time (~70 ns). Both of these effects are consistent with the higher attenuation associated with tissue and the heterogeneity of the tissue in the path to the kidney.

Acoustic cavitation

What is acoustic cavitation?

A second mechanical force generated by lithotripter shock waves is *acoustic cavitation*. This refers to the generation of cavities in a fluid (i.e. bubbles) when the tensile phase (negative pressure) of the acoustic wave is sufficiently strong to rip the fluid apart. In lithotripsy the tensile phase of the shock wave is large enough (~10 MPa) to generate violent cavitation events. Cavitation is believed to play a significant role in tissue damage during SWL and to contribute to stone comminution [38–44].

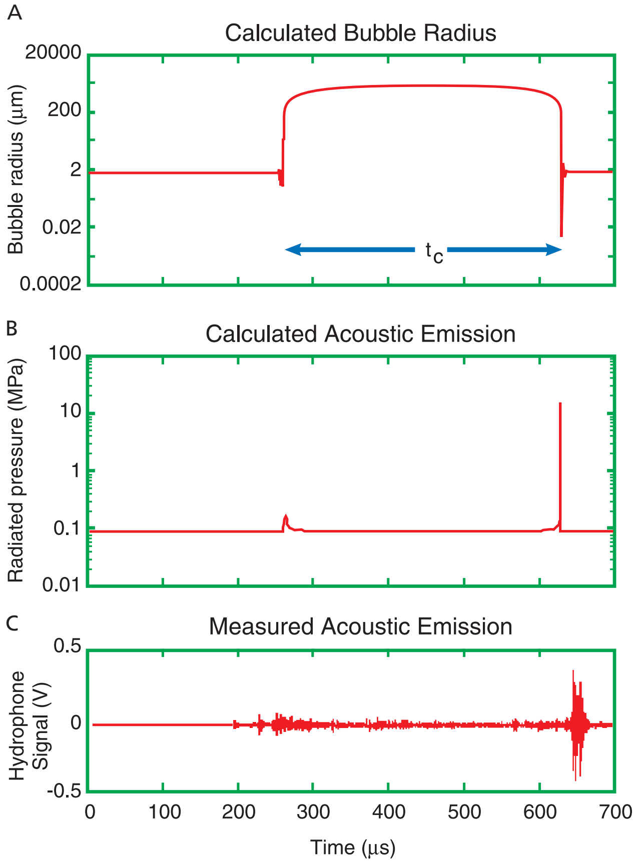

Figure 49.10 (A) Calculated radius versus time curve of a spherical bubble subjected to a lithotripter pulse (as in Figure 49.1). In this time scale the shock wave arrives at the focus at 250 µs and the bubble is initially crushed by the leading compressive phase. The bubble grows to a millimeter at about 450 µs. It then starts to collapse with a violent collapse occurring at 650 µs. The time between the two collapse signals is the characteristic time (t_C). (B) Predicted acoustic emissions that the bubble calculated in A will radiate. There are two emissions due to the two collapses. (C) Measured acoustic emissions in a Dornier HM3 using a passive cavitation detection (PCD) (see Figure 49.11). The measured emissions agree with the calculations.

Typically, cavitation is initiated at micron size motes in the fluid or at sites of small gas pockets trapped on rough surfaces [45]. There are a number of different theories [46, 47] that can describe how acoustic cavitation proceeds once the cavity has been formed (at this point the cavity is normally referred to as a bubble). In Figure 49.10 the predicted radius is shown of a spherical bubble as a function of time in response to a lithotripter shock wave. The bubble is first compressed by the positive phase of the shock wave. Then the tensile phase of the shock wave causes the bubble to grow from 1 µm radius to about 1 mm radius over a period of 150 µs. Note that the bubble continues to grow long after the shock wave has passed (5 µs time frame), referred to as inertial cavitation, as the dynamics of the bubble are no longer driven by acoustics but instead by the inertia of the fluid surrounding the bubble. While the bubble is large, some amount of gas and vapor from the fluid will diffuse into the bubble. The bubble will then collapse by virtue of the near vacuum inside the bubble and the roughly 1 atm of ambient pressure in the surrounding fluid. It takes a further 150 µs for the bubble to collapse. The collapse is very violent and the gas that diffused inside is heated and compressed to such an extent that it can produce light [48]. The main collapse is followed by rebounds after which the gas that had diffused into the bubble will slowly diffuse back out into the fluid. Also shown in Figure 49.10 is the acoustic emission radiated by the bubble; a lithotripsy-induced cavitation bubble generates two acoustic emissions, one when it is hit by the compressive wave and one when it collapses hundreds of microseconds later. This unique "double-bang" signature can be used to detect the cavitation events [48].

Measuring cavitation

There are numerous techniques by which cavitation can be measured:

High-speed photography

Bubble behavior can be observed using a high-speed camera in an *in vitro* setting [49–52]. In principle this allows the entire dynamics of a bubble to be tracked from genesis to extinction, but in practice this is not feasible. During the growth phase the bubble needs to be imaged at millimeter length scales and tens of microsecond time scales. At the nadir of the collapse, the bubble radius is less than 1 µm and the dynamics of the collapse is at nanosecond time scales. The remnant bubble left after the rebounds is of the order of 10 µm and slowly dissolves over hundreds of milliseconds. Thus, the range of temporal and spatial scales makes it virtually impossible to capture all the bubble dynamics photographically. Therefore, investigators have found it necessary to study cavitation in segments. A further limitation of imaging is that cameras have a limited depth of field and cannot give an adequate record of bubble dynamics throughout the substantial volume of the cavitation field.

Laser scattering of single bubbles

The dynamics of a single spherical bubble can be measured very precisely by laser scattering [53]. In this case, a laser beam is used to illuminate a bubble and a photodetector is used to collect the light scattered by the bubble. For a spherical bubble, the amplitude of the scattered light varies in a known way as the bubble radius changes. This method is able to capture most of the temporal and spatial scales associated with the dynamics of a lithotripsy-excited cavitation bubble. However, laser scattering has several restrictions; the sample volume is very small, the method requires unrestricted visual access at high magnification, and the theory that is used to recover the actual bubble size is based on a single spherical bubble. This means the technique will only yield qualitative information about bubble clouds or nonspherical bubbles, both of which are very common in lithotripsy-induced cavitation.

Acoustic detection in vivo

Acoustic detection of bubbles is very powerful, in part because it can be used to characterize bubble dynamics within living subjects. Acoustic detection normally works in one of two modes: active cavitation detection (ACD) and passive cavitation detection (PCD) [54–56]. In ACD one transducer is used to send an acoustic wave toward the cavitation field, while a second transducer picks up sound reflections from the bubbles; this is the acoustic analog to laser scattering. In PCD, one or more receiving transducers listen for the "double-bang" acoustic emissions from cavitation bubbles (Figure 49.11). In the case where two receiving transducers (dual PCD) are used, it is possible to take advantage of coincidence detection to sample a small, discrete volume of the cavitation field where the transducers intersect [57]. The timing and amplitude of the two emissions is influenced by various factors such as the size of the initial bubble and the amplitude of the lithotripter pulse.

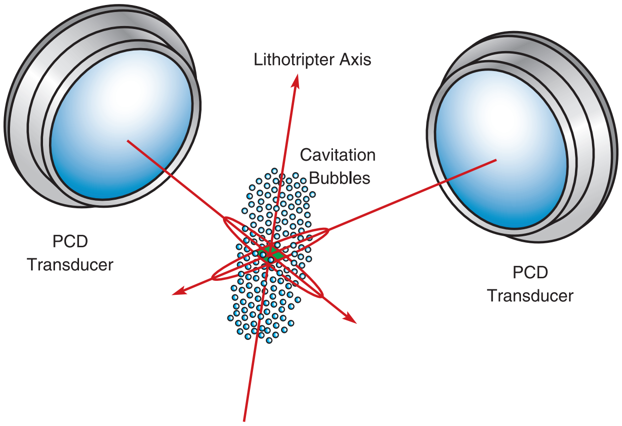

Figure 49.11 Dual passive cavitation detection system. Two focused transducers are placed so that their ellipsoidal focal zones intersect. Acoustic emissions that occur in the shaded region of intersection can be localized by searching for simultaneous events on both transducers.

Thus, although acoustic detection does not image bubbles (i.e. it cannot provide information on bubble number and size), it gives valuable data that can be used to help characterize the acoustic output of a lithotripter and assess the environment and dynamics of the cavitation field [51, 57, 58].

Other techniques have also been developed for measuring cavitation. It has been observed that cavitation leads to pitting on metal foils and the number and depth of pits can be used to assess the violence of cavitation [38, 59, 60]. An electromagnetic probe device has been used to measure the mechanical force exerted on a steel ball by both the incident shock wave and the cavitation activity [61]. The high pressures and temperatures in the interior of the bubble provide an environment which can produce light emissions (sonoluminescence) and also result in enhanced chemical reaction rates (sonochemistry). Production of light and by-products from chemical reactions have both been used to quantify cavitation activity [53, 58]. These are secondary measurements of the cavitation field and interpreting the results in terms of physical processes can be complicated.

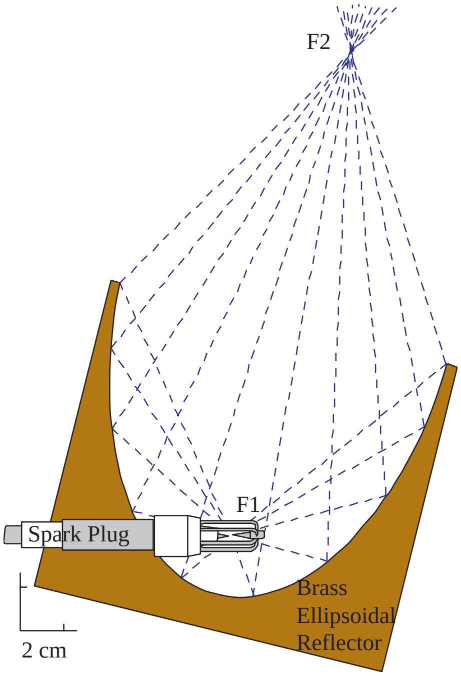

Figure 49.12 Focusing design of a Dornier HM3 electrohydraulic lithotripter. A spark plug is located at the focus (F1) of an ellipsoidal reflector. Energy from the spark plug is reflected and focused to the second focus of the ellipsoidal reflector (F2).

Physics of clinical lithotripsy

Shock generation and focusing

Three shock-wave generating principles have been used in clinical lithotripters.

Electrohydraulic lithotripters

The electrohydraulic lithotripter (EHL) has a spark source which generates a shock wave that is focused by an ellipsoidal reflector (Figure 49.12). In an EHL the pressure pulse originates as a shock wave and remains a shock wave at all times during its propagation from the spark source to the reflector, and then as it focuses to the target. As will be shown below, this is not the case for other types of shock-wave sources. In an EHL, focusing of the shock wave is critically dependent on the placement of the spark at the first focus of the ellipse. Misalignment by just a few millimeters can lead to a significant loss in focusing, and a lengthening and broadening of the focal zone. Thus, EHLs are designed so that the alignment of the electrode is consistent. Still, there is variability in the precise location of the spark discharge across the spark gap that is not easy to control. Therefore, from shot-to-shot there can be significant variation (upwards of 50%) in the amplitude of the shock wave and there can be some shift in the position of the focal zone at the target. A unique "feature" of EHLs is that the target is insonified by two pulses. The main focused pulse is preceded by the so-called "direct wave," which travels directly from the spark to the target without bouncing off the reflector. The direct wave arrives about 30 µs earlier and, because it undergoes spherical spreading, it is low in amplitude. However, it has been shown that this direct wave can influence the cavitation generated by the focused wave [62].

In EHL the electrodes wear out and must be replaced. Some lithotripter manufacturers have found ways to enhance the lifetime of their electrodes, such as by encapsulating them and filling the casing with an appropriate electrolyte [63]. Still, electrodes eventually show wear and this can affect their acoustic output.

Electromagnetic lithotripters

The electromagnetic lithotripter (EML) uses an electrical coil in close proximity to a metal plate as an acoustic source. When the coil is excited by a short electrical pulse, the plate experiences a repulsive force and this is used to generate an acoustic wave. If the metal plate is flat, the resulting acoustic wave is a plane wave that must then be focused by an acoustic lens (Figure 49.13A). If the plate is in the shape of a tube, the resulting cylindrical wave can be focused by a parabolic reflector (Figure 49.13B). In both cases, focusing is very reproducible and variation in measured pressure waves is less than 10%. Thus, the shock waves generated by EMLs are

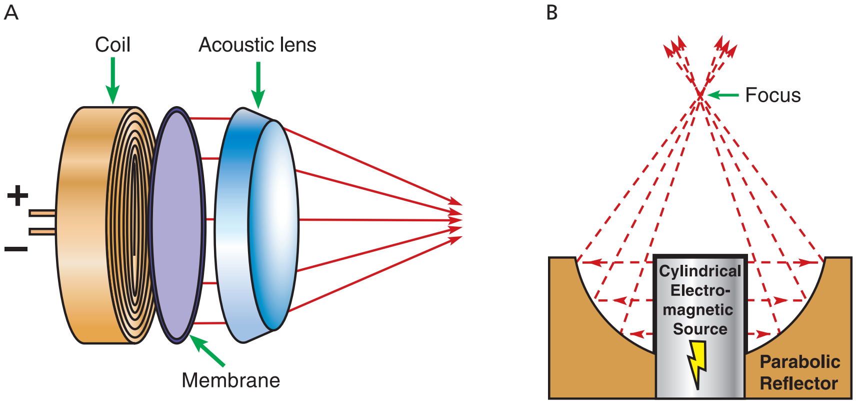

Figure 49.13 The two focusing mechanisms employed in electromagnetic lithotripters. (A) In a Siemens lithotripter, a membrane is driven by a coil to produce a plane wave, which is then focused by an acoustic lens. (B) In a Storz lithotripter, a coil excites a cylindrical membrane, which generates a wave that is focused by a parabolic reflector.

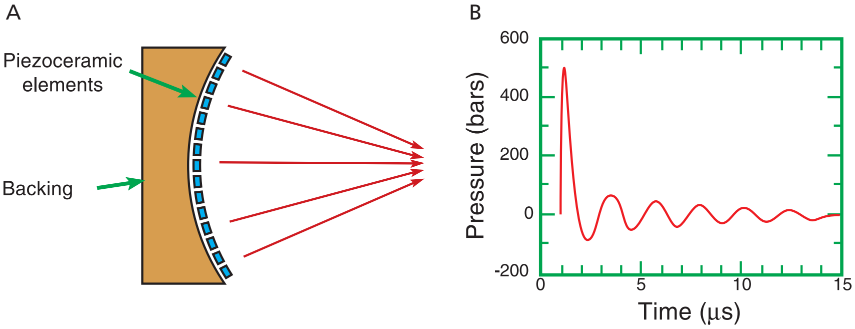

Figure 49.14 (A) Fundamental principles for a piezoelectric lithotripter. Piezoceramic elements are placed onto the surface of a sphere. The wave will focus to the center of the radius of curvature of that sphere. (B) Typical waveform measured at the focus of a piezoelectric lithotripter. Note the long ringdown for time greater than 3 μs.

inherently more consistent than in EHLs. An additional advantage is that there are no electrodes to replace.

One difference between the acoustics of an EML and an EHL is that the acoustic pulse generated by an EML does not start as a shock wave; the displacement of the plate generates a high-intensity ultrasonic wave, which has a smooth waveform with no discontinuities. The amplitude of the wave at clinically relevant power settings is normally high enough that nonlinear distortion occurs during propagation, and a shock is produced before the wave reaches the focus. One exception is a broad focal zone EML which does not produce a shock at the focus [64]. A second difference is that the EML waveforms have a relatively small trailing positive pressure after the negative phase (this can be observed at about 6 μs in Figure 49.2). This peak likely has little impact on the stress inside the stone but may affect the cavitation dynamics.

Piezoelectric lithotripter

The piezoelectric lithotripter (PEL) uses piezoelectric crystals to form an ultrasonic wave. When a voltage is applied to a piezoelectric crystal, it deforms and creates an acoustic wave. The crystals are placed on the inside of a spherical cap and the acoustic wave focuses at the centre of curvature of the sphere (Figure 49.14A). This focus is highly reproducible and very small variations in the focal waveforms are reported. Similar to the EML, the acoustic waveform in PEL starts as an acoustic pulse and a shock wave is created by nonlinear propagation distortion. For most clinical settings a shock is produced before the wave reaches the focus. Figure 49.14B shows a representative waveform from a PEL [65]. One significant difference from an EHL or EML waveform is the presence of a tail or coda at the end of the pulse. This is because the piezoelectric crystals "ring" for a couple of cycles after they are excited, a phenomenon not present in an EHL or EML. The coda at the end of the PEL pulse probably has a minimal effect on the stress induced in a kidney stone but may affect the cavitation dynamics.

Coupling of the shock source to the body

Efficient transfer of acoustic energy from one medium to another only occurs when the acoustic impedances are very close. A water–tissue interface results in very good coupling and theoretically it should be possible to transfer more than 99% of the energy of the shock wave into the body. However, the presence of even a small pocket of air at the skin surface will result in a dramatic reduction in energy transfer to the patient (see Figure 49.4). Thus, the manner in which the shock wave is coupled to the body is critical.

Water-bath lithotripters

The "first-generation" lithotripters (e.g. Dornier HM3) were EHLs and used an open water bath in which the patient was immersed. Thus, there is nothing but water between the shock source and the patient. This is ideal except that bubbles that drift up from the spark gap or the cavitation bubbles that form along the path of the shock wave, have the potential to collect against the skin of the patient and interfere with the propagation of subsequent shock waves. To help prevent this, the ellipsoidal reflector of the shock source is fixed off vertical (in the Dornier HM3 the angle is 14°) and the water in the bath is continuously degassed.

Dry lithotripters

Most current lithotripters have the shock-wave source mounted in a "therapy head" which is filled with water. The therapy head is capped by a thin rubber membrane, which is pressed against the patient and through which the shock wave passes. The water in the therapy head of most lithotripters is continuously recirculated and degassed to remove any bubbles that might interfere with the shock-wave propagation. Although this design is more convenient in the clinic than a water-bath-type lithotripter, it is inherently less effective at allowing shock waves to pass because the presence of the rubber (although well matched to water and tissue) adds additional reflecting interfaces. A coupling agent such as gel or oil is used to marry the rubber membrane of the treatment head to the skin [66]. Although seemingly simple, this procedure may spell success or failure for treatment. Laboratory studies have shown the coupling interface to be prone to developing voids and such defects covering just 10% of the interface can reduce the breakage efficiency of model stones by around 60% [23]. The typical methods used to apply gel, such as dispensing from a squeeze bottle and rubbing by hand across the skin and treatment head, create defects and are highly variable. An improved method for coupling has been described [22].

Focal zone of the lithotripter

In lithotripsy, acoustic energy is focused to a relatively small focal zone surrounding the focal point of the lithotripter. The *focal point* is a geometric point in space, e.g. in an EHL this point is the second focal point (F2) of the ellipsoidal reflector [24], and it is usually the location at which the stone is placed for treatment. All lithotripters have a focal point, but lithotripters differ in the dimensions of the zone of high pressure (*focal zone)* that surrounds this point. The dimensions and the pressure characteristics of the focal zone are the most important features that distinguish one lithotripter from another.

There are many definitions of the focal zone that may be appropriate for lithotripsy. The IEC standard for measuring lithotripter pulses [20] defines it as the volume within which the measured peak acoustic pressure is at least half the maximum peak positive pressure. The peak positive pressure (p+) of a waveform (see Figure 49.1) is the highest positive pressure in that waveform. The maximum peak positive pressure is the highest value of p+ in the field of the lithotripter and the location of the maximum peak positive pressure is defined as the focus [20]. The maximum peak pressure will vary with the power setting of the machine. The resulting focal zone is normally an elongated, elliptical, "cigar-shaped" volume. It is worth noting that maximum peak pressure does not necessarily occur at the same location as where the manufacturer indicates a stone should be placed, and that the location of the focus and the dimensions of the focal zone may change as the power setting is changed.

The Dornier HM3 has arguably been studied and characterized more extensively than any other lithotripter. As such, data for the Dornier HM3 are a useful standard for reference. Because different lithotripters, even the same type of lithotripter, may perform somewhat differently, and because investigators have used different means to map the acoustic field of their lithotripters, published values for peak pressures and dimensions of the focal zone of a given type of lithotripter may not coincide perfectly. Representative focal zones of selected lithotripters are shown in Figure 49.15. Typical published values for the Dornier HM3 EHL report the maximum peak positive pressure to be 40 MPa at 20 kV and the focal zone to be about 60 mm long by 12 mm in diameter. In contrast the Storz Modulith EML has a maximum peak positive pressure around 100 MPa at energy level 8 and a focal zone that is about 35 mm long and only 4 mm in diameter. Reported values for PELs indicate a maximum peak positive pressure of 80 MPa and a focal zone 20 mm long and 3 mm in diameter [67, 68]. Thus, there is a considerable difference in the dimensions of the focal zone between lithotripters and those lithotripters with the narrowest focal zone have the highest peak pressures.

The half-maximum focal zone (also known as –6 dB focal zone as the contour corresponds to the pressure being 6 dB less than at the maximum) is recommended

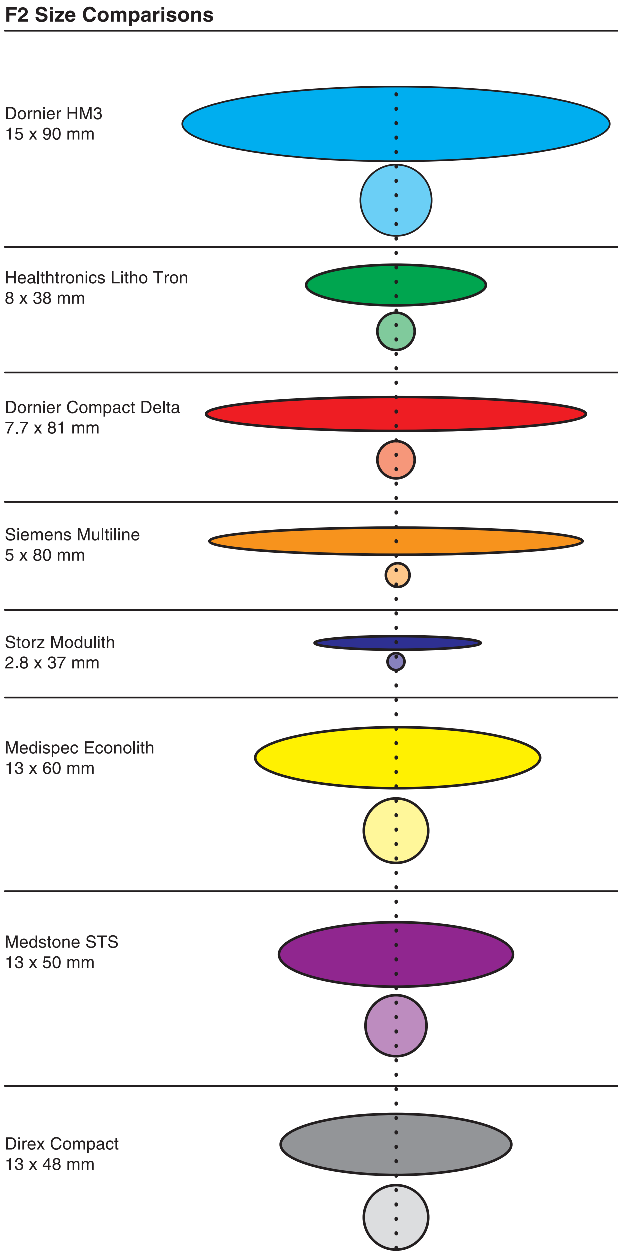

Figure 49.15 Comparison of the focal zones of selected clinical lithotripters showing their dimension along the axis of the lithotripter (ellipses) and in the focal plane at the focus (circles) (image courtesy of P. Blomgren).

in the IEC standard, but this may not necessarily be the best descriptor of the focal zone of a lithotripter. For example, in a Storz lithotripter, with a peak pressure of 110 MPa at energy level 9, the focal zone will correspond to the region where the peak pressure exceeds 55 MPa. For a Dornier HM3, which only has a peak pressure of 40 MPa, the focal zone will correspond to a region where the pressure exceeds 20 MPa. Therefore, when comparing the focal zones of these machines the absolute pressure levels are very different; indeed, the focal zone of a Dornier HM3 would be zero if the 55 MPa level of the Storz focal zone were used. Other suggestions for the focal zone include: half the peak negative pressure, half the energy density, the surface where the peak pressure is 5 MPa, or even using the energy that passes through a volume with a diameter of 10 mm (about the size of a typical stone). Until there is a better understanding of how shock waves fragment stones, it is unlikely that an alternative metric will be agreed upon within the literature.

The smaller, tighter focal spot of an EML or PEL would at first glance appear to be advantageous as it should allow for more accurate targeting on the stone, and thus, less damage to the surrounding tissue. However, *in vitro* experiments (where stones are stationary) indicate that the EMLs or PELs, with their very high pressures, are no better at breaking stones that an EHL and often are not as effective [69, 70]. High peak positive pressure does not appear to correlate with enhanced stone fragmentation in the clinic [4, 15, 16].

Further, stone motion due to respiration means that with a tight focal zone fewer shock waves actually hit the stone and more shock-wave energy is deposited directly into tissue [71]. When it is considered that some tight focal zone lithotripters have peak pressures in excess of 100 MPa, this suggests that tissue is being subjected to a very high dose of acoustic energy. This may help explain the increased incidence of adverse effects such as subcapsular hematomas observed with these machines [6, 13].

Device equivalency/equating lithotripter performance

At present there are no agreed metrics by which the acoustic output of different lithtotripters can be compared, and there is no straightforward means to operate a given lithotripter so that it is equivalent to another. This is partly due to the fact that, although all lithotripters produce shock waves that have similar waveforms, the amplitude and focal zone of different lithotripters is not the same, and measurements of the properties of the acoustic field can yield very different values. This is illustrated in Table 49.1, where a number of physical measurements made on an EHL and an EML are shown [72]. For the settings chosen, the only parameter that was roughly equivalent was the energy incident on a 6.5-mm diameter stone (0.484 mJ vs 0.528 mJ). However, other physical measurements varied tremendously, e.g. the peak positive pressure in the EML was three times that of the EHL.

Therefore, although it is possible to find settings on two given machines that give equivalency on one physical property, it is unlikely that there will be equivalency on other properties and, indeed, there is likely to be significant differences. For example, if the power setting

Table 49.1 Comparison of physical properties measured in an electrohydraulic lithotripter (EHL) and an electromagnetic lithotripter (EML) [53]. The columns show measurements of the length and width of the focal zone, the peak pressures (p+ and p–), the energy in the focal zone (E_{FZ}) (Eq 49.9 using the area given by width of the focal zone), the energy incident on a stone (E_{STONE}) (Eq 49.9 using the area with diameter of the stone 6.5 mm), and the characteristic time of cavitation, which is a measure of the strength of cavitation. The bottom row shows the ratio of the values in the EHL to the EML. For the settings used here, the energy delivered to the stone was the one quantitative parameter that was approximately equivalent.

	Length_{FZ}	Width_{FZ}	p+	p–	E_{FZ}	E_{STONE}	t_C
EHL	54 mm	9 mm	37.5 MPa	–7.8 MPa	4.25 mJ	0.484 mJ	250 µs
EML	32 mm	3.5 mm	115 MPa	–14.6 MPa	3.35 mJ	0.528 mJ	350 µs
Ratio	1.69	2.57	0.33	0.53	1.27	0.92	0.71

were to be reduced on the EML to yield the same pressure as the EHL, then the energy measurements would drop by almost a factor of 10.

A further confounding issue is the number of shock waves to be used. The clinical literature suggests that typically fewer shock waves are required to break stones on an EHL in comparison to an EML. In addition, the rate at which shock waves are delivered has also been reported to affect fragmentation efficiency [73]. Therefore, at the current time there is no clear way in which the three main parameters of shock-wave delivery for a lithotripter (power, number of shock waves, and rate of shock-wave delivery) can be adjusted to ensure equivalency between different machines.

Mechanisms of shock-wave action

Acoustic waves in stones

A number of mechanisms have been proposed by which lithotripsy shock waves may destroy kidney stones. The acoustic field in stones is more complex than the acoustic theory described for shock waves in tissue. Kidney stones are elastic solids and support two types of waves: a longitudinal or compression wave (which is akin to an acoustic wave) and transverse or shear waves, where the motion of the vibration is transverse to the direction of propagation. In a shear wave, the transverse vibration does not result in the molecules being compressed and rarefied, but rather they oscillate in a manner analogous to the wave motion of a rope excited by a snap of the wrist. Longitudinal waves and shear waves travel at different speed and the longitudinal wave speed (c_L) is always faster than the transverse wave speed (c_T).

When a shock wave passes from urine or tissue into a stone, the transmitted energy is divided between the longitudinal and transverse waves in the stone. How the shock-wave energy is divided between the longitudinal and transverse waves depends on the material properties of the stone and the angle of incidence. If the wave is normally incident on the stone surface, then all the energy is converted into a longitudinal wave in the stone and no energy is available for transverse waves. As the angle of incidence increases, less energy is converted into a longitudinal wave and more is converted into transverse waves. The complex shape of many natural stones results in a nontrivial partition of energy between the two types of wave.

The basic features of the interaction of shock waves with a stone can be illustrated by means of a computer simulation. The computer simulation solves the equations of motion for particles in an elastic solid [17]. Figure 49.16 shows a series of snap-shots of the interaction of a lithotripter shock wave with a cylinder-shaped stone. The snap-shots show the distribution of the maximum tensile stress inside the stone at each instant of time. In the first two frames, the shock wave can be seen to enter the stone as compressional waves. The third and fourth frames show that the longitudinal wave inside the stone and the acoustic wave outside the stone result in the generation of shear waves from the lateral walls. Further, between the third and fourth frames, the shock wave reflects from the rear wall. Because the impedance of the surrounding fluid is less than that of the stone, the reflected pressure wave is inverted (because the pressure reflection coefficient R_P given in Eq 49.19 is negative if $Z_2 < Z_1$) and the leading compressive wave is reflected as a tensile wave. The last two frames show constructive interference between the shear and longitudinal waves to produce the high tensile stresses in the stone.

Acoustic properties of stones

From the point of view of determining the stress inside a kidney stone, the important material properties are: density (ρ_0), longitudinal sound speed (c_L), and shear wave velocity (c_T). Figure 49.17 shows reported measurements from human stones [74–77]. There is a large variation in the reported properties for uric acid, calcium oxalate monohydrate, and cystine stones, e.g. the sound speed in calcium oxalate monohydrate varies between 3000 m/s and 4500 m/s. This variation is likely due to

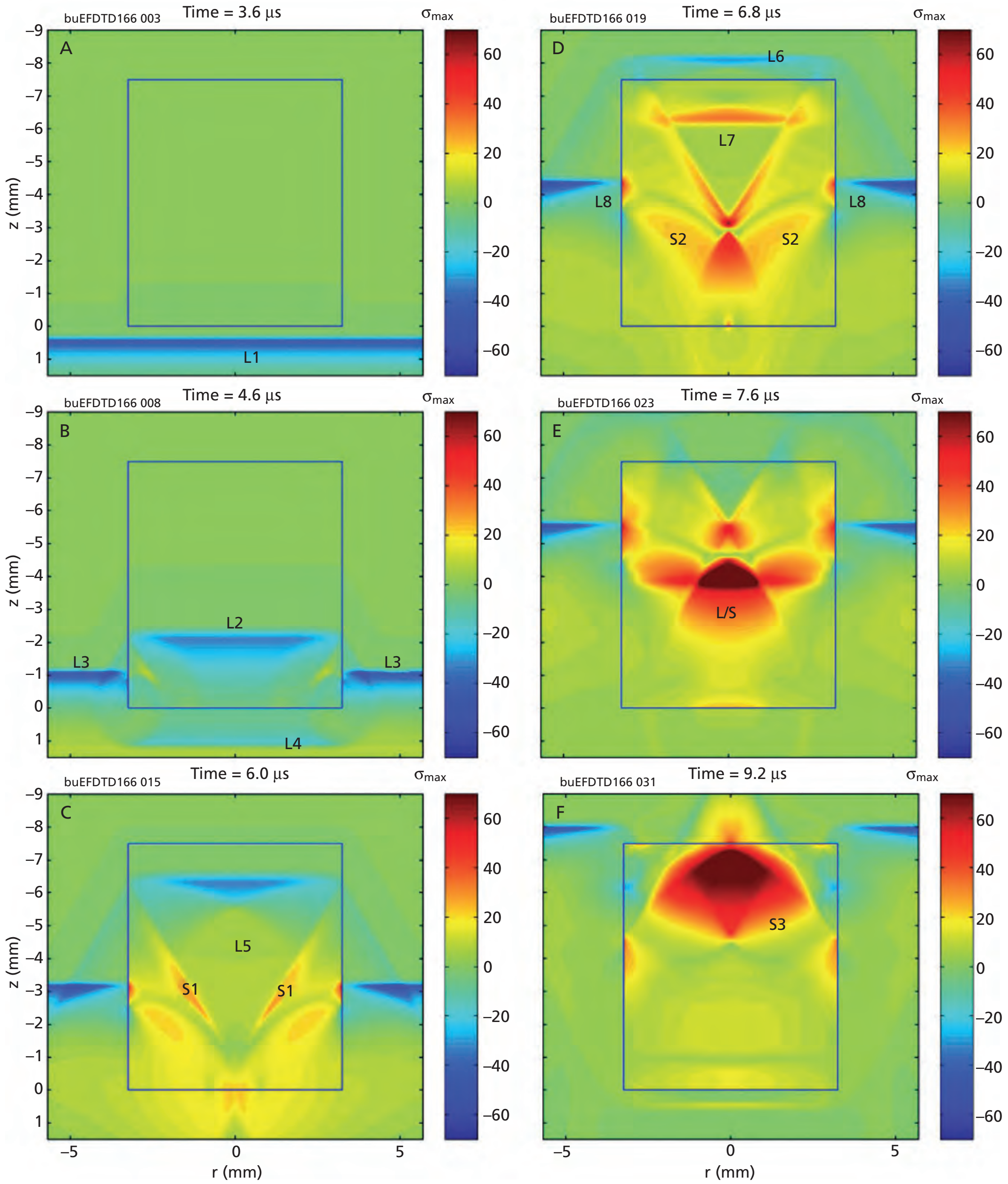

Figure 49.16 Snap-shots of the tensile stress generated by the propagation of a lithotripsy shock wave through a model kidney stone surrounded by fluid. The cylindrical stone (6.5 mm wide × 7.5 mm high) has the following properties $\rho = 1700\,\text{kg/m}^3$, $c_L = 3000\,\text{m/s}$, $c_S = 1500\,\text{m/s}$. The shock wave is incident from below and the color scale depicts the tensile stress (in MPa), where yellow through red indicate regions of tensile stress, and blue regions of compression. (A) (at 3.6 μs) The leading compressional phase of the shock wave in the fluid (L1) is almost incident on the proximal surface of the stone. (B) (4.6 μs) The shock wave has entered the stone as a longitudinal wave (L2). Note because the propagation axis is normal to the surface, no shear waves are generated at this interface. Because the speed in the stone is higher than in the fluid, the wave in the stone advances ahead of the wave in the fluid (L3). The reflection of the shock wave by the proximal surface can be seen leaving the bottom of the image (L4). (C) (6.0 μs) The tensile tail of the incident shock wave can be seen in the stone (L5) following the leading compressive phase. The interaction of the longitudinal wave in the stone with the lateral walls of the stone results in the production of shear waves (S1) that propagate towards the axis of the stone. (D) (6.8 μs) The leading compressive phase has been partially transmitted (L6) and reflected (L7) at the distal surface. The reflection coefficient is approximately −0.5 and results in a tensile phase (L7) that generates significant tensile stress (red region) near the distal surface; this is spall. The wave on the outside of the stone (L8) is inducing further shear waves (S2) inside the stone. (E) (7.6 μs) The reflected longitudinal wave and the shear waves interact to produce a large region of tensile stress in the center of the stone (L/S). (F) (9.2 μs) The shear waves interact near the distal surface to generate another region of high tensile stress (S3).

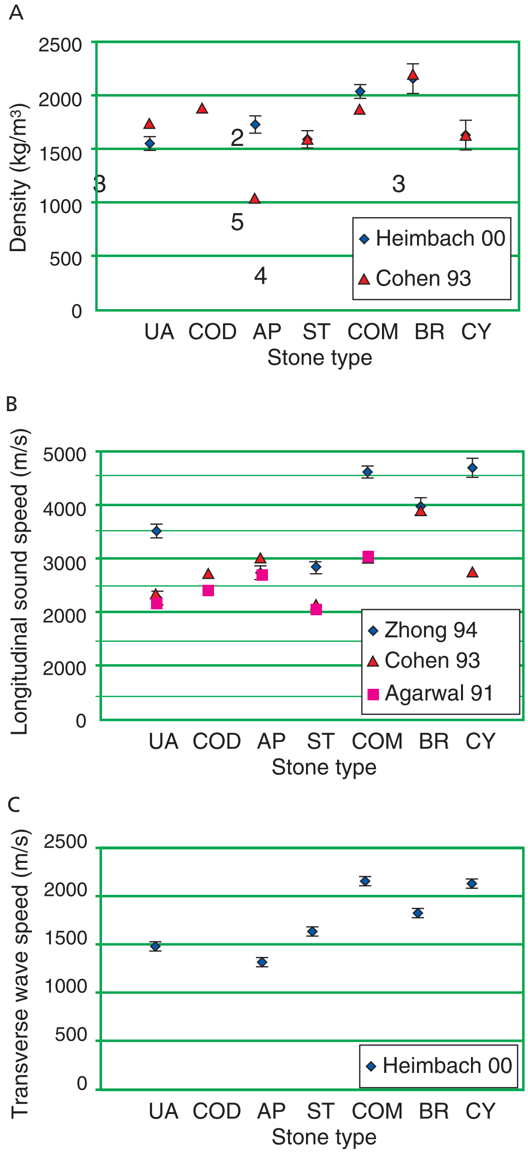

Figure 49.17 Reported measurements of acoustic properties in human stones [74–77]. (A) Density, (B) sound speed, (C) shear wave speed. UA, uric acid; COD, calcium oxalate dihydrate; AP, apatite; ST, struvite; COM, calcium oxalate monohydrate; BR, brushite; CY, cystine.

the natural variation in the properties of the stones, but may also be related to the preparation of the stones (e.g. amount of hydration).

How shock waves break stones

Numerous mechanisms by which shock waves may fragment stones have been described in the literature. It is likely that some combination of these mechanisms plays a role in the actual fragmentation process. Here, we give a synopsis of some of the most likely mechanisms (Figure 49.18).

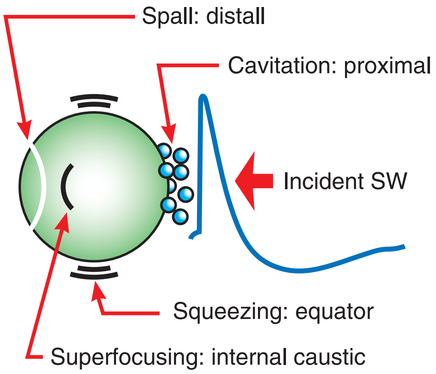

Figure 49.18 Regions where different stone fracture mechanisms will act.

Spall fracture

Spallation occurs after the shock wave enters the stone and subsequently reflects from the rear of the stone (see Figure 49.16). The stone–urine interface inverts the large positive pressure pulse, resulting in a large tensile stress. This stress is added to the tensile stress of the, still incoming, negative pressure tail, resulting in a very large tensile stress near the back wall [78–81]. Most solids are much weaker in tension than in compression, so the large tensile stress near the rear of the stone can be expected to make the material fail. Recent fundamental research suggests that spall plays a small role in the fragmentation of kidney stones [17, 19]

Squeezing

Squeezing occurs because of the difference in sound speed between the stone (>2500 m/s) and the surrounding fluid (~1500 m/s). The shock wave inside the stone "runs away" from the shock wave propagating through the fluid outside of the stone (see Figure 49.16B,C). The shock wave that propagates in the fluid outside the stone results in a circumferential force on the stone (known as a hoop stress). It has been proposed that this will result in a tensile stress at the proximal and distal ends of the stone and lead to an axial "splitting" failure [82]. More recent dynamic studies suggest that squeezing produces shear waves that then produce high tensile stresses internal to the stone towards the distal surface [17]. It is these regions of high tension associated with shear waves that appear to correlate best with *in vitro* stone fragmentation [19].

Shear stress

The shear waves and compressive waves that propagate inside a kidney stone (see Figure 49.16) will generate regions of high shear stress in the stone. Figure 49.19 shows *in vitro* experiments in which regions of high

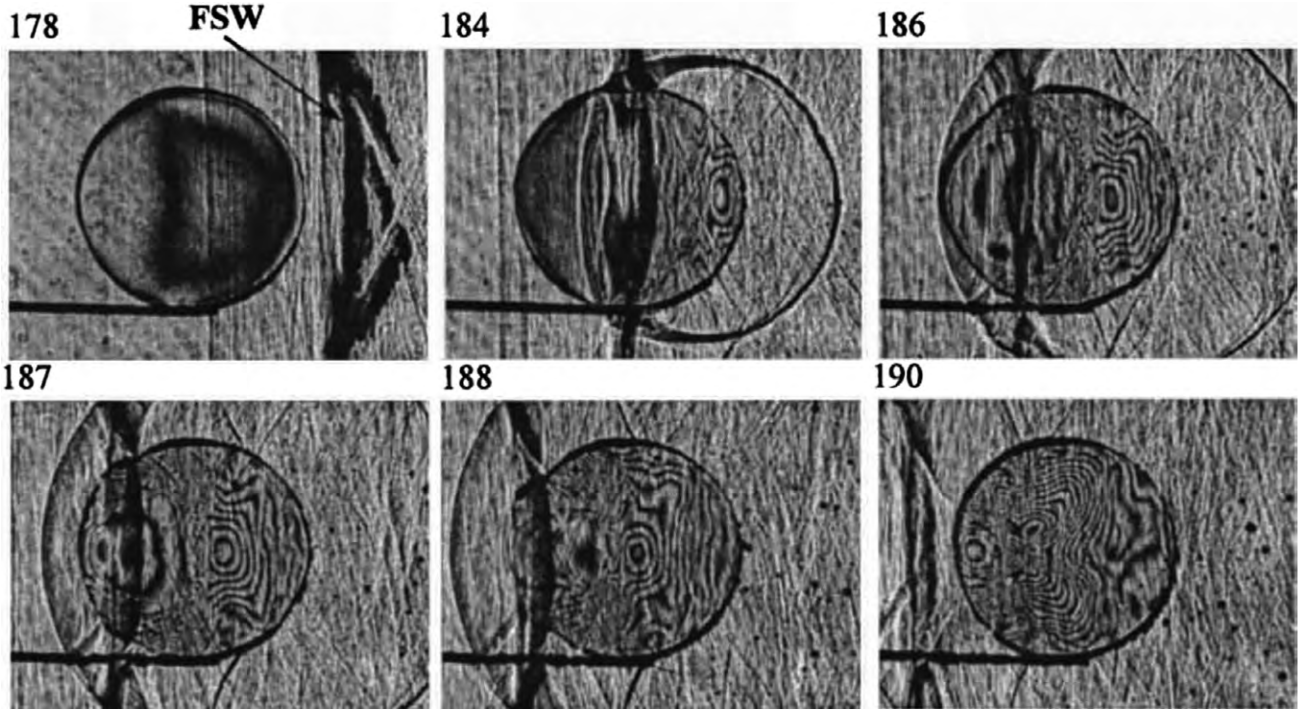

Figure 49.19 Stress waves in cylindrical stone (14-mm diameter) which was subject to a shock wave (moving from right to left) for a Dornier HM3. At 178 µs the shock wave is almost incident on the stone. At 184 µs the shock wave has entered the stone and has also reflected. At 186 µs the compressive phase of the shock wave has just made it to the distal surface of the stone and a shear wave can be seen at the mid point of the stone. At 187 µs the compressive wave has exited the stone and the shear wave is focused along the axis of the stone. At 188 µs the shear wave reaches the distal surface of the stone. At 190 µs the shock wave has passed by the stone and there is still reverberation inside the stone. (Reproduced from Xi and Zhong [84], with permission. Copyright © 2011 Acoustical Society of America).

shear in a stone can be visualized. Many materials are weak in shear, particularly those that have layers. In the case of kidney stones that consist of layers, the bonding strength of the matrix between the layers often has a low ultimate shear stress [78, 79, 83, 84]. Further, the organic binder of kidney stones is much softer than the crystalline phase, and as the shock front passes through the stone, it will induce very large shear stresses at the binder–crystal interfaces which likely contribute to the fracture of the kidney stone [85].

Superfocusing

Superfocusing is the amplification of stresses inside the stone due to the geometry of the stone. The shock wave that is reflected at the distal surface of the stone can be focused either by refraction (associated with the high sound speed and geometry of the stone) or by diffraction from the corners of the stone. It has been shown that these reflected waves can be focused to caustics (regions of high stress) in the interior of the stone and that this can lead to failure [84, 86]. The regions of high stress (both tensile and shear) can be determined from the geometry of the stone and its elastic properties, e.g. density, longitudinal wave speed, and shear wave speed.

Cavitation

Cavitation refers to small bubbles/cavities that grow in the urine surrounding the stone in response to the large negative pressure tail of the acoustic pulse. When a cavitation bubble collapses near a solid surface (e.g. a kidney stone), a microjet of fluid is formed that pierces the bubble and impacts the surface (Figure 49.20) with speeds upwards of 100 m/s [39]. This jet likely plays a role in cavitation-induced damage to kidney stones [39–40]. The collapse of the cavitation bubble also results in the emissions of secondary shock waves [87, 88] that are radiated into the stone. These secondary shock waves have an amplitude comparable to that of the focused shock wave [89].

In vitro experiments where cavitation is suppressed show significant reduction in stone fragmentation [59, 90, 91]. Cavitation is principally a surface-acting mechanism, and experiments indicate that it acts most strongly on the proximal (shock-wave incident) surface of the stone [40, 80, 92]. Studies suggest that cavitation is

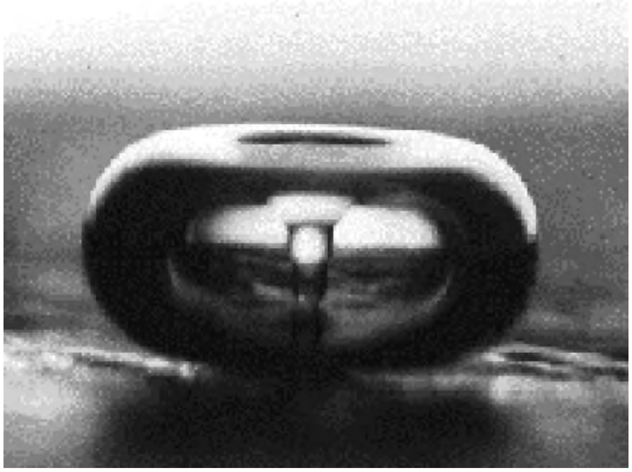

Figure 49.20 Cavitation bubble collapsing on a metal surface [27]. A jet of fluid can be seen punching through the center of the bubble toward the metal surface (courtesy of Dr L. A. Crum).

perhaps most effective once stones have been broken into fragments less than 3–4 mm in diameter [93], as this is a size where direct stress effects are less important and cavitation has more surface area to act upon.

It has also been suggested that the stresses imparted by cavitation can act by a spall mechanism [86, 94]. Also it has been recognized that the cavitation generated by lithotripters acts as a cluster of bubbles (Figure 49.21) rather than individual bubbles, and that the coherent collapse of the cluster may enhance the destructive power of cavitation [52, 95, 96].

Fatigue

Fatigue is a process that may occur anywhere in the stone. Its hallmark is the progressive development of cracks [97–98]. The cracks are nucleated at sites of small imperfections that occur in almost all materials; these nucleation sites will be present in all kidney stones. The imperfections are sites of "stress concentrations" which, when a shock wave passes, can lead to local stresses far in excess of the average stress induced by the shock wave [99]. These very high stresses can cause the imperfections to grow into micro-cracks with the passage of a number of shock waves. With subsequent shock waves, the micro-cracks grow into macro-cracks and eventually produce cracks large enough to induce failure. The cracks can be grown either by large tensile stresses or by large shear stresses. Therefore, fatigue will be enhanced wherever regions of high stress coincide with weak points in the stone. This means that there could be a synergistic effect between fatigue and some of the other mechanisms that result in localized regions of high tensile or shear stress. There are two pieces of evidence that strongly support the argument that stone comminution is a fatigue process. First, the internal structure of stones has been shown to affect how they fragment in lithotripsy [100–103]. Second, normally more than 1000 shock waves are required to progressively fragment stones into sufficiently small pieces; the use of multiple stress cycles to fracture a material is a classic hallmark of fatigue [97, 98].

Although, present understanding of SWL indicates that the stones fail through a fatigue process, it is not clear which mechanism drives the fatigue. The two most commonly cited mechanisms are direct stresses (tension and shear) and cavitation, or some combination of them [93]. Part of the problem in determining which mechanism is in action is that only limited data on the material strength of kidney stones has been reported, e.g. ultimate strength in compression, fracture toughness, Knoop hardness, and Vickers micro-hardness [74–76, 104–107]. Of note is the paucity of data for the tensile and shear strength of kidney stones. This is most likely because determining these properties in brittle materials is fraught with technical difficulties. Further, most of the data have been measured in quasi-static tests, with the stress applied over many minutes, and the results may not be representative of the material properties when subject to shock waves, where the stress is applied and removed in microseconds [85]. At present the data on material strength of kidney stones are insufficient for the fracture process to be described.

Mechanisms of tissue damage

It is now well recognized that SWL results in trauma to the kidney, and that in some cases the injury can be severe [9]. The clinical implications of such adverse effects are still under investigation and a thorough discussion of the complications associated with lithotripsy is given in Chapter 53.

The notion that lithotripter shock waves can pass harmlessly through the body is simply not true. It is likely that all patients who receive at least an average dose of shock waves (2000 shock waves at mid-range power or higher) experience some degree of tissue trauma. Lithotripsy has been very beneficial for a large number of patients, but it has also led to severe, even catastrophic adverse effects for others [9, 11, 108]. To better understand how shock waves have the potential to cause tissue trauma, the physics of the problem needs to be considered.

As discussed above, lithotripters produce a focused acoustic pulse. The acoustic field is broad at the source and narrow at the focus. The focal zone, the area of highest acoustic pressure, is elongated and of dimensions that cannot be localized exclusively to a stone.

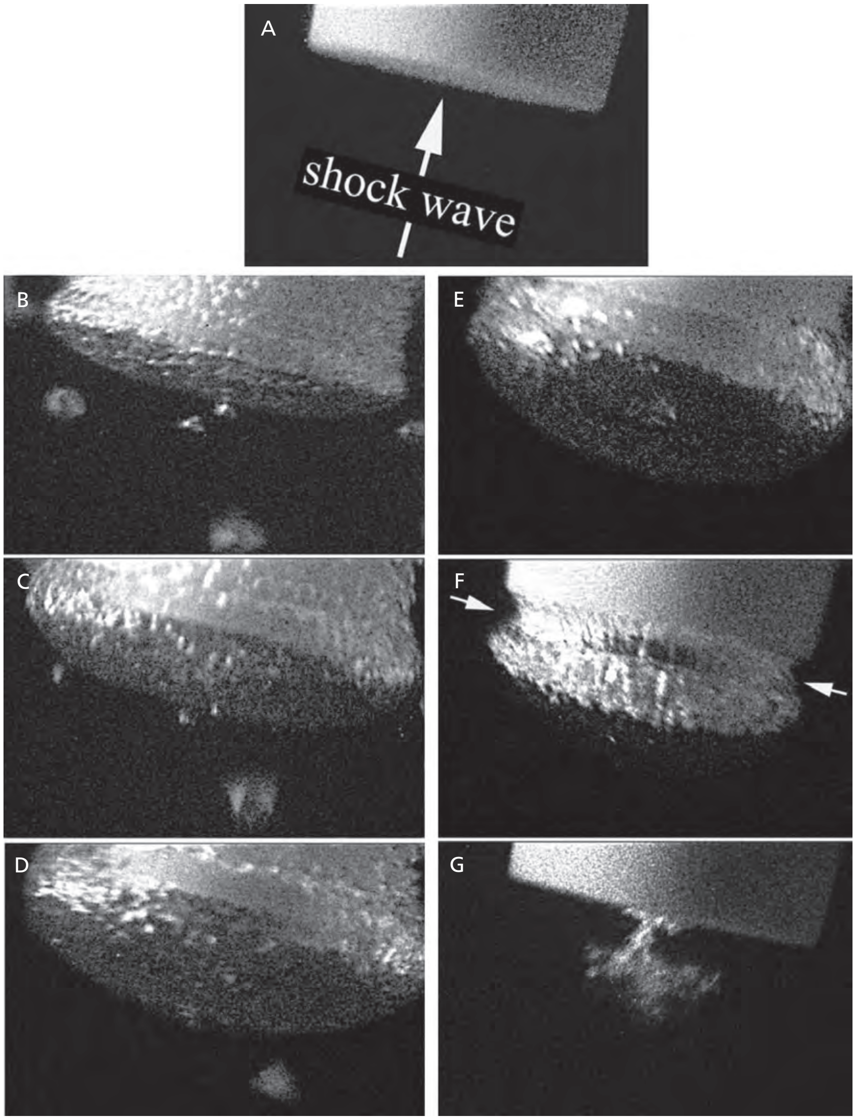

Figure 49.21 Cavitation bubble cluster collapse on a stone 6.5 mm in diameter × 7.5-mm long. (A) Orientation of shock wave to stone. (B) 100 µs after shock-wave arrival a bubble cluster has formed on the proximal surface and a few bubbles have formed in the surrounding fluid. (C–-E) (200, 300 and 400 µs after shock-wave arrival, respectively) the cluster continues to grow. (F) The cluster begins to collapse in a mushroom-like shape. (G) Final collapse of the cluster at the centre of the stone (reproduced from Pishchalnikov *et al*. [52] with permission).

Although shock waves are targeted onto the stone, the surrounding tissue is also subject to significant mechanical forces. The length of the focal zone of most lithotripters is about 50 mm (see Figure 49.15) and this means that the entire thickness of the kidney is subject to high amplitude shock waves. In addition, patient motion, due to respiration or discomfort, likely results in the stone spending a good portion of the treatment time out of the focal region and, thus, many of the shock waves will interact solely with tissue.

Fortunately, tissue has physical properties that make it far less susceptible to damage by shock waves than kidney stones. For example, the fact that the acoustic impedance of tissue is close to that of water means that shock waves can pass through a tissue–water interface without significant reflection. Thus, tissue is not subjected to the extreme tensile forces that cause stones to fail. Further, the sound speed in tissue is almost constant and so tissue will not be subject to squeezing, which can generate tensile and shear stresses. However, tissue is subject to deformation by the pressure wave and to cavitation induced by the tensile phase of the shock wave. We briefly describe the mechanisms that maybe contribute to tissue injury.

Mechanical stress

The positive pressure of a lithotripter pulse leads to significant compression of tissue. The fact that the shock rise time *in vivo* is of the order of 70 ns means that the spatial extent of the shock front is about 100 µm. Therefore, tissue structures in the range of 10 µm to 1 mm will experience a significant variation in stress across them as the shock wave passes. The short rise time associated with the shock will lead to nonuniform straining of the tissue, resulting in shear forces. It is generally recognized that tissue structures are sensitive to shear stress and the distortion of the tissue by the shock wave could induce enough shear to cause damage [109, 110].

Cumulative shear

As mentioned above, the positive phase of the shock wave can induce a displacement in tissue of tens of microns. The tissue returns to its original state during the negative phase. However, there can be a small net displacement remaining in the tissue after the passage of the shock wave. Eventually the elasticity of the tissue will relax the tissue back to its state. However, for kidney tissue it has been estimated that this time scale may be of the order of 1 s [111]. This means that for shock waves that are delivered at rates faster than 1 s, i.e. faster than 60 shock waves/min, the tissue will not have time to return to its rest state before the next shock wave is delivered. Over thousands of shock waves the net displacement could build up to sufficient levels to result in tearing of the tissue: a process referred to as cumulative shear [111].

Shear induced by inhomogeneities

Tissue is an inhomogeneous medium at multiple length scales. Spatial variation in the sound speed on the millimeter length scale can have a dramatic effect on the focusing of ultrasonic pulses in tissue [112]. As the shock wave focuses, parts of the wavefront that passed through tissue with high sound speed will be advanced and the parts that passed though low sound speed tissue will fall back. This distortion in the wavefront will lead directly to shear stresses in the tissue. Again, these shear stresses could be strong enough to induce mechanical damage of the tissue [109].

Cavitation

Cavitation is known to occur in tissue during lithotripsy [51, 113–115]. Measurements using passive cavitation detection in both humans and pigs have detected the unique acoustic signature associated with cavitation. Measurements have indicated the presence of cavitation in the perirenal fat, collecting system, parenchyma, and subcapsular hematomas.

Cavitation has been well documented to have a significant biologic effect in many *in vitro* settings [116–121]. Experiments in lithotripsy indicate that damage to *in vitro* cells and *in vivo* tissue is dramatically reduced when cavitation is reduced or eliminated [42, 121, 122]. This makes cavitation the most likely candidate for tissue damage in tissue. The onset of detectable cavitation in the parenchyma requires about 1000 shock waves to be delivered using a Dornier HM3 in the pig model [115]. This is consistent with the approximately 1000 shock-wave dose needed to observe widespread damage in the pig kidney for the same shock-wave settings [9]. These data suggest that in SWL widespread damage to the kidney can be attributed to cavitation.

For cavitation bubbles to undergo a violent growth and collapse cycle, the bubble needs to be in a fluid environment. This implies that cavitation activity, at least initially, is more likely to occur in the fluid environment of blood vessels than within the surrounding tissue. There are at least two mechanisms by which bubbles could produce mechanical damage to vessel walls and once a vessel is ruptured it is likely that cavitation activity progresses quickly.

Bubble expansion Bubbles may rupture vessel walls during the expansion phase of the bubble cycle. That is, as the negative pressure of the shock wave passes through the vessel it causes the bubble to undergo explosive growth (see Figure 49.10) pushing outward on the vessel and rupturing it. Experiments using cellulose tubes as capillary phantoms in an *in vitro* setting support the explosive bubble hypothesis [123, 124]. However, measurements of bubble activity in isolated mesentery vessels suggest that bubble growth results in little distention of vessel walls and that bubble collapse is more likely to result in injury for thin-walled vessels particularly, such as venules [125].

Bubble collapse When cavitation bubbles collapse near rigid surfaces they can form high-velocity microjets that are forceful enough to etch metal surfaces (Figure 49.20). These jets would also appear to be capable of puncturing the wall of a capillary or other blood vessel; however, bubble dynamics near elastically “soft” boundaries do not result in jetting towards the surface. High-speed movies of bubble activity in mesentery vessels found no evidence of jetting towards the wall [125]. Rather the dominant effect of the collapsing bubbles was to produce a focal invagination of the order of 10 µm, with deformation that has the potential to induce vessel rupture.

Cavitation progression Once blood vessels have been ruptured, either by mechanical stresses or cavitation bubbles inside intact vessel, blood will collect in pools, e.g. in a hematoma, and there is a greater potential for cavitation to occur. The pooling of blood provides a large fluid-filled space for cavitation bubbles to grow and collapse. Also, existing bubbles, which can act as nuclei for subsequent cavitation events, will not be swept away by blood flow, but will remain in the pooled region. This explains the intense PCD cavitation signals and B-scan ultrasound echogenicity collected from hematomas during SWL [113, 114, 126]. The ensuing violent cavitation could result in liquefaction of the tissue and the spread of a wave of cavitation-induced damage through the kidney [127].

Research continues in this area with the goal of confirming whether the physical processes outlined here, or some other processes, are responsible for tissue damage in SWL. This is partly due to the fact that the mechanical response of the tissue, at least at strain rates relevant in SWL, is not well understood, and so damage criteria are also not well defined. Further, there are few experimental systems that can be used to test and validate different hypotheses. Although the general consensus among researchers is that cavitation is the primary mechanism for tissue injury, this field still requires much study.

Evolution of the lithotripter

It is more than 30 years since the introduction of lithotripsy to clinical practice and there have been a number of noteworthy changes in equipment design, but none that has involved a fundamental change in the acoustics of the lithotripter. That is, lithotripters have changed (they are now compact, modular, use dry shock heads, have improved imaging), but the acoustic signature of the lithotripter pressure pulse remains the same. The focal waveform generated by a Dornier HM3 is virtually the same as the waveform produced by any of the numerous lithotripters available on the market today. This is not to imply that the lithotripter industry has been static. Indeed, there has been a very active effort on the part of manufacturers to produce machines that are easier and more practical to use. In this regard lithotripsy has seen numerous refinements. At the same time, however, it is essential to note that success rates in lithotripsy have declined [4, 15–16]. One refinement was to develop lithotripters that produced a tight focal zone of high peak positive pressure. However, as discussed above, data suggest that this led to decreased efficiency of stone breakage and to an increase in collateral damage. More recently, manufacturers have developed lithotripters with broader focal zones [128–130] or in the case of the Storz SLX-F2, a user-selectable focal zone. This is an example of progress in lithotripsy which comes at the expense of poorer outcomes and it appears that a step back is now being taken.

The first lithotripters were electrohydraulic devices in which the shock wave was generated by underwater spark discharge and shock-wave coupling was achieved by immersion of the patient in a water bath. The Dornier HM3 was a very popular lithotripter of this era, and at some centers is still in use today. By today's standards the Dornier HM3 produces moderate peak positive pressures (~40 MPa) delivered to a generous focal zone (~12 × 60 mm). The Dornier HM3 was a very successful machine and it is probably safe to say that the early success and rapid acceptance of lithotripsy was built on the back of this particular lithotripter.

Even though the Dornier HM3 was a very effective lithotripter, it was perceived by some to have several significant drawbacks. It used an open water bath to couple shock waves to the body; treatment was painful, necessitating that the patient be sedated or even anesthetized; the shock wave firing had to be gated to the cardiac cycle (to reduce risk of arrythmias), which slowed the treatment; and the lithotripter was a large, stationary piece of equipment that required a dedicated water treatment plant. What physicians (and patients) really wanted was lithotripsy that was painless, fast, and convenient with minimal to no anesthesia; a fully ambulatory walk-in-walk-out therapy. Lithotripter manufacturers responded with a number of modifications. Problems related to the overall physical design of the lithotripter were challenging but solvable. For example, the issue of the open water bath was addressed by enclosing the shock head and by using a rubber membrane to couple the shock wave to the body. This was not a perfect solution, as there is no better way to achieve acoustic coupling than through a water–tissue interface [23]. However, elimination of the water bath meant that medical staff had much easier access to the patient, the lithotripter did not necessarily have to be tied down to a dedicated facility, and lithotripters could be designed as modular systems. Many modern lithotripters have been designed to be portable and are used in mobile lithotripsy units.

The cardiac gating was found to be unnecessary for most patients and so most lithotripters run in "ungated" mode in which the urologist can chose the rate at which shock waves are delivered. Commonly, this will be at a rate of 2 Hz or 120 shock waves/min, which results in a much quicker treatment time. However, *in vitro* studies indicated that firing at higher rates resulted in worse stone fragmentation [131]. The likely explanation for this effect is that bubbles from a previous shock wave can last for many seconds [91] and that these bubbles can end up shielding the stone from the next shock wave [132]. The *in vitro* studies were followed up by animal studies which confirmed better stone comminution at slower rates [73]. A number of clinical trials have reported data on the effect of rate and a meta-analysis of those studies indicates that firing at a lower rate does result in improved stone comminution [133]. Further data in the pig model indicate that delivering shock waves more slowly results in less tissue damage [64]. It may also be that at slower rates the cavitation bubbles from the previous shock have more time to dissipate and in addition cumulative shear should produce less damage [111].

The attempt to design a lithotripter so that it can be operated "anesthesia free," on the other hand, has proven to be a much more difficult problem. Discomfort during shock-wave treatment is due primarily to the sensation of cutaneous pain over the area of shock-wave entry at the surface of the body. One attempted solution was to widen the aperture at the shock source in order to spread the energy over a broader area. A wider aperture broadens the acoustic field along the shock-wave axis, but it narrows the focal zone of the pressure pulse. Many current lithotripters have a very narrow focal zone, of the order of 5 mm or less. Some of these lithotripters also generate huge peak positive pressures (in excess of 100 MPa). Because of respiratory motion, shooting at a stone using a narrow focal zone proves to be harder than when using a broad focal zone. Even if the shock wave could be kept directly on target, use of a narrow focal zone is less effective at delivering energy into the stone. Further, regardless of which lithotripter is used, lithotripsy is uncomfortable for the patient. If the patient is not sedated they will move to try to get more comfortable. Thus, attempts to build a totally anesthesia-free device have not yet been successful.

Another perceived disadvantage of the Dornier HM3 was the limited lifespan of the electrodes; it is necessary to replace the electrode one or more times during a treatment. EMLs and PELs do not use electrodes, which is an advantage in terms of cost, time, and convenience. In addition to the need to periodically change electrodes, electrode wear is an issue with EHLs. As the spark gap widens with use, there is increased variability in the path of the arc discharge. Also, as the spark gap widens, it takes higher a voltage to initiate a spark. Several manufacturers of current EHLs have found various ways to improve electrode life and some use designs such as encapsulation in an electrolyte-filled housing that extend the life of the electrode [17, 134].

Future directions in lithotripter design

More recent developments in lithotripsy could herald a positive change for the future of SWL. That is, there has been an effort to introduce novel approaches in lithotripter design that build upon well-tested theory and positive experimental results, targeting ways to improve stone breakage and reduce tissue injury. One approach is a response to the recent trend toward tight focal zone, high acoustic pressure machines. The Xi Xin-Eisenmenger lithotripter (Model CS-2012) is a wide-focus and low-pressure lithotripter that generates the largest focal zone (18 × 180 mm) and lowest range of acoustic pressures (10–25 MPa) currently in use in clinical practice [128]. This machine was developed to test the hypothesis that a very broad focal zone could be used to enhance stone breakage by circumferential squeezing [82]. It has been reported in an early trial that this machine delivers a high stone-free rate (86%) and can be used anesthesia free [128].

Cavitation control may be a means to improve lithotripsy. The cavitation bubble cycle, i.e. the time for a bubble to grow and then collapse, lasts of the order of 300 μs in the free field and ~600 μs at the surface of a stone [135]. Studies have shown that cavitation bubbles generated by one lithotripter pulse can be manipulated by a second pulse [136, 137]. If the second pulse arrives while bubbles are in their early growth phase, further expansion is stopped and the bubbles collapse with minimal damage. If, however, the second pulse arrives later in the cycle, bubble collapse is accelerated and damage is enhanced. Thus, the timing of the two pulses is critical. Bailey originated dual-pulse lithotripsy and in his studies used twin shock sources oriented coaxially facing one another [138]. Others have built upon this concept and have developed lithotripters that fire multiple pulses along the same axis [41, 139–140] or machines that use dual treatment heads offset at an angle to accommodate the constraints imposed by the anatomy of a patient [141–143]. At the current time, dual-pulse lithotripsy is under development and testing. The concept holds promise, as this may be a means to tailor acoustic forces within the focal zone for better breakage of stones, hopefully with reduced collateral damage [144, 145].

The safety of lithotripsy is a very important issue. Shock waves cause trauma and any strategy that lowers the dose of shock waves needed to treat a patient should be welcomed. One way to reduce unnecessary shock wave impact on tissue is to track the stone during treatment and to only fire when the shock wave will hit the stone. Devices have been proposed which monitor stone location and only allow shock waves to be fired when the stone is at the focus of the lithotripter [146–150]. A device has also been proposed to exploit acoustic time-reversal to dynamically change the focus of the lithotripter and so hit the stone even as it moves [151, 152]. Such concepts have the potential to dramatically reduce the number of shock waves required to break a stone. However, clinical devices do not currently employ real-time tracking.

Conclusions

SWL is a superb example of the successful transition of engineering technology into the clinical area. We have outlined the underlying acoustic principles that describe: the generation of the shock pulse, focusing, nonlinear distortion, coupling of the shock source to the body, and absorption of sound by the body. The exact mechanisms by which shock waves can damage stones and tissue are still not fully understood, although it is likely that direct stresses and cavitation are dominant in stone fragmentation and that cavitation is dominant in tissue injury. Improvements in lithotripsy, whether through improved use of existing lithotripters or through the development of new technologies, are likely to come only from an improved understanding of the acoustics and the physics of this problem.

In this chapter we have attempted to make the following main points:

- Most lithotripters produce a similar type of shock wave, which consists of a leading positive pressure shock front (compressive wave), lasting about 1 μs, followed by a negative pressure trough (tensile wave), which lasts about 3 μs. There is a large range in the amplitude of the shock waves used with peak positive pressures of 30–110 MPa, depending on the type of shock source and the power setting.
- Various types of shock-wave sources and focusing mechanisms have been exploited in lithotripsy. EMLs and EHLs dominate the lithotripsy market today.
- The size and dimensions of the focal zone are controlled by diffraction. Typically, EMLs have a smaller focal zone than EHLs and generate substantially higher peak positive pressures. A smaller focal zone is not necessarily an advantage as patient motion means that the stone can easily spend a significant amount of time outside the focal region. Currently, there is no good metric to determine equivalent action of different types of machines.
- Shock waves are coupled into the body using a water path that ideally is devoid of bubbles. Most current lithotripters use an enclosed water path in which the shock head is capped by a rubber membrane of low acoustic impedance. Such dry lithotripters tend not to be as efficient as the older water-bath lithotripters in which the patient is immersed in water during treatment. This reduced efficiency could be due at least in part to poorer coupling. Coupling can be improved by minimizing handling of the gel.
- The acoustic properties of tissue are very close to those of water, but tissue absorption and inhomogeneities lead to modest reduction of the peak positive pressure of the shock wave at the kidney. This is a significant finding for it validates *in vitro* experimentation as being representative of the *in vivo* condition.
- It appears that multiple mechanisms are responsible for stone fragmentation. Most likely shear waves generated at the outer surface of the stone generate high tensile stresses to induce the first fractures. Then cavitation grinds down the fragments into pieces small enough to pass.
- For tissue injury it appears that once detectable cavitation occurs, the kidney tissue suffers widespread damage. The initiation of detectable cavitation appears to be associated with rupture of smaller order vessels and this may be due to mechanical rupture of the vessel wall by direct stress or by localized invagination induced by a collapsing bubble.
- Firing shock waves more slowly results in better stone comminution and reduced tissue damage.
- Since its inception, lithotripsy has undergone a fascinating evolution. Water-bath-type, EHLs have given way to modular, highly portable lithotripters, many of which employ electromagnetic shock-wave generators. Most lithotripsies are now performed using mobile units delivered by truck to subscribing hospitals. This improved convenience has come at a price, as stone retreatment rates have increased and reports of collateral damage are on the rise. One explanation is that the newer lithotripters are not as efficacious and have the potential to cause more collateral damage.
- New technologies of shock-wave delivery are now being applied to patient treatment. Dual-pulse lithotripsy uses two shock heads to fire separate pulses with the potential for control over the properties of the acoustic field leading to improved efficacy and safety. Likewise, initial success with a new lithotripter that produces a very broad focal zone and is operated at low peak positive pressures suggests that a return to some of the features of the original lithotripter could also be a step toward improved lithotripsy.

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CHAPTER 50

Lithotripsy Systems

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History of extracorporeal shock-wave lithotripsy

Urolithiasis was documented by the ancient Egyptians, thousands of years BC. It is a common affliction, affecting as many as 15% of humans during their normal lifespan, irrespective of age, gender or ethnicity. Although mortality from stone disease is rare, its morbidity and economic impact are considerable [1, 2].

Prior to the introduction of extracorporeal shock-wave lithotripsy (ESWL) and other minimally invasive techniques, such as percutaneous nephrolithotomy (PCNL) and ureterorenoscopy (URS), open surgery was the principal treatment modality for urolithiasis. The advent of ESWL revolutionized modern stone management.

As early as 1963 physicists at Dornier, an aircraft manufacturer in Friedrichshafen, Germany, investigated the impact of raindrops on flying objects, as these were causing shock waves that not only damaged the outer shell of airplanes but also internal structures. During these experiments, an engineer accidentally discovered the effects of these shock waves on biologic tissue. At the same time, the German Ministry of Defense was showing interest in the interaction between shock waves and biologic tissue. In 1974, a partnership to conduct research on the application of shock waves in humans was formed between Dornier Development and Research (W. Hepp and G. Hoff), the Department of Urology at the Ludwig–Maximilians Universität in Munich (E. Schmiedt and F. Eisenberger), and the Institute of Surgical Research at the same university (W. Brendel and Ch. Chaussy). Funding was obtained through the German Research and Technology Ministry [3–5].

Early on it was found that shock waves caused no damage when travelling through muscle, fat or connective tissue, except at transition zones with high acoustic impedance. It was proposed that shock waves could be used to fragment kidney stones [3, 4]. In the first experiments, a light-gas gun was used to elicit a shock wave in an open waterbath containing a stone. With a focused wave it proved possible to fragment the stone. To obtain optimal propagation of the shock wave through human tissue, water was chosen as the coupling medium: water has acoustic properties nearly identical to those of human tissue. It also proved easy to generate shock waves under water using the discharge of an electrode in a semi-ellipsoid reflector.

The original idea was to fragment a stone with one single shot. Therefore, the energy needed to produce a shock wave that could do and for safety, the effect of such a shockwave on biological structures needed to be determined [6]. Furthermore, the shock-wave circuit needed to produce the underwater spark gap discharge, the electrode or spark gap itself, and focusing using a semi-ellipsoid reflector were investigated. The first shock-wave lithotripter, TM1, was built.

It was realized that imaging was needed to properly position the stone to be fragmented in the second focus of the semi-ellipsoid reflector. A second lithotripter, TM2, with an improved shock-wave generator and an ultrasound A-scanner integrated into the ellipsoid was

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built. With the ultrasound technology available at that time, however, it proved virtually impossible to adequately target kidney stones *in vivo*.

In the early animal experiments a form of "carpet bombing" was used to fragment stones *in vivo*. The important conclusions of these experiments were that [3, 4]:

- Stone fragmentation with high-energy shock waves and without direct contact with the shock wave source was possible.
- Trauma to the kidney and the surrounding tissues could be excluded.
- Spontaneous passage of the fragmented stones was possible, provided the fragments were small enough.
- Ultrasound technology at that time did not allow proper targeting *in vivo*.

Although not easily integrated into the experimental lithotripter, fluoroscopy was then chosen to target the stones: two conventional X-ray C-arms were incorporated in the lithotripter.

Further *in vitro* studies of the capacity of shock-wave generators showed that generators with a lower capacity produced complete and fine fragmentation at much lower energy doses than those with higher capacity.

The first lithotripter for human treatments, Human Model 1 or HM1, was built in 1979. Patient selection for the first treatments was very strict:

- A radio-opaque stone not larger than a cherry stone in the renal pelvis;
- Unobstructed urological tract;
- No urinary tract infection;
- No comorbidities.

The first patient was successfully treated on a Dornier HM1 by Christian Chaussy, B. Forssmann, and D. Jocham in 1980 [7]. The results of the first clinical study on 221 treatments in 206 patients were published in 1982 [8].

To propagate the new technique as reproducible and safe, the HM1 needed several improvements:

- Improved X-ray system;
- Improved patient support;
- Improved installation to provide the 1200 L of degassed water for the waterbath;
- Improved shock-wave generator;
- An ellipsoid with a treatment depth of 13 cm.

The Dornier Human Model 3 (Dornier HM3) was born.

In 1983 the second lithotripsy center worldwide was opened in the Department of Urology (F. Eisenberger) of the Katharinen Hospital in Stuttgart, Germany. In 1984 the first Dornier HM3 in the USA was installed in the Methodist Hospital in Indianapolis, IN, USA (Daniel M. Newman and James E. Lingeman). A study for marketing approval by the Food and Drug Administration (FDA) was monitored by Georges Drach [9]. The rest is history …

Lithotripters were originally devices dedicated to ESWL. Modern stone management demands a judicious combination of endourologic techniques and ESWL, and there is an evolution towards the construction of multifunctional urologic workstations.

Components of a lithotripter

The Dornier HM3 represented the archetype of the first-generation lithotripter and was characterized by a large water bath in which the patient was immersed for optimal shock-wave coupling. Equipped with an electrohydraulic shock-wave source and an ellipsoidal reflector with a small aperture to focus the shockwave, the treatment required general or spinal anesthesia. With bidirectional fluoroscopic imaging system, the stone could be targeted and be in the therapeutic focus F2. Multifunctional or multidisciplinary use was not possible. The results achieved with this device are still considered the baseline for comparison in evaluating all new devices.

Second-generation lithotripters utilize an electrohydraulic, electromagnetic, or piezoelectric shock-wave source. Transmission of the shock wave is achieved with a water cushion or partial water bath. The stone is localized with an ultrasonic or fluoroscopic imaging system [10–13]. The anesthesia requirements usually are limited to intravenous sedation. Multifunctional or multidisciplinary use is limited.

Third-generation lithotripters are also equipped with an electrohydraulic, electromagnetic, or piezoelectric shock-wave source. All systems allow anesthesia-free treatments. They use fluoroscopy and ultrasound, alternately or simultaneously, to target the stones. Finally, all components are integrated into a multifunctional system with a treatment table, allowing both ESWL and endourologic procedures to be performed with the same device.

Shock-wave sources

Shock waves are acoustic waves, which are mechanical waves consisting of pressure and density variations which can travel through media in any phase, i.e. gas, liquid, or solid. They are also referred to as pressure waves as they propagate through a medium by alternating decompression and compression of the medium. At media interfaces, absorption, reflection or refraction of the shock waves can occur [14]. An acoustic wave of very short duration is called an acoustic pulse and a shock wave is a very short acoustic pulse. Positive pressure rises to maximum in a very short time, followed by a short phase of negative pressure. As the wave propagates through the medium, it becomes ever steeper until it forms a shock wave, which is characterized by a sudden drop from positive to negative pressure. The short phase of negative pressure generates cavitation in the transmission medium. The bubbles induced by cavitation subsequently collapse violently and create microjets or secondary shock waves. For medical purposes, shock waves are generated in water and transmitted into the patient's body using a (partial) water bath or a water cushion for coupling. Water is chosen as the transmission medium as it has comparable acoustic properties to those of human tissue, leading to impedance matching with low reflection at the contact surface between the water bath or water cushion and the patient.

In the Dornier HM3, the first commercially available lithotripter, shock waves were generated using an electrohydraulic shock-wave source. In second- and third-generation lithotripters any of the three types of shock-wave generation are used: electrohydraulic, electromagnetic, and piezoelectric.

Electrohydraulic shock-wave sources

Electrohydraulic shock-wave generation

Electrohydraulic shock-wave generation is based on an underwater spark discharge. A spark plug with two opposing electrode tips is positioned in the focus F1 of an ellipsoidal reflector. A capacitor of about 100 nF connected to the spark gap is charged to a voltage of 15–30 kV and then abruptly discharged, producing a fast expanding plasma channel between the electrode tips, and resulting in rapid vaporization of the surrounding water, like a microexplosion. This releases a spherical shock wave that is reflected by the wall of the ellipsoidal reflector towards the therapeutic focus, F2, of the reflector. The intensity of the shock wave can be adjusted by changing the discharge voltage. The treatment depth and focusing are defined by the geometric parameters of the ellipsoidal reflector.

This type of shock wave is still used in lithotripters today, and the shock wave source of the HM3 is still considered to be the most effective of this type. Electrohydraulic shock waves have the disadvantage that the lifespan of the electrode tips is limited to several thousand shocks; degradation of the electrode tips causes output variations and instabilities of the focal position.

Electroconductive shock-wave generation

To compensate for the degradation of the electrode tips, EDAP TMS developed a modified electrohydraulic generator, the DIATRON IV, an electroconductive shock-wave generator.

The electroconductive generator is a 100 nF generator connected to an electrode immersed in a highly conductive solution instead of degassed water. Due to the better conduction of electricity, this highly conductive solution allows an extremely accurate spark position. The interelectrode distance is reduced to 0.25 mm and can be adjusted to compensate for electrode wear. This spark gap technology also allows the generation of a focal zone that varies in size with the power output. An automatic pressure regulator permanently adapts the voltage input to consistently deliver the requested pressure and also controls the total energy delivered to the patient.

Electromagnetic shock-wave sources

"Flat coil" electromagnetic shock-wave emitter

The electromagnetic shock-wave emitter (EMSE; Dornier, Siemens) features a flat coil that generates a strong magnetic field when a high current pulse flows through it. This field causes an isolated metallic membrane to be repelled into the surrounding water, the water in the vicinity of the membrane is compressed, and a plane acoustic pulse is released and focused into the therapeutic focal area by a lens. The pressure across the membrane surface is essentially constant. During propagation to the focal area, the pressure pulse undergoes nonlinear effects, leading to the generation of a shock wave. Specifically, the pulse's rising slope becomes steeper and the pulse duration becomes shorter. Since the electromagnetic shock-wave generation principle does not rely on the dielectric breakdown of a liquid, all the associated threshold effects and arc-forming instabilities are avoided. An EMSE can therefore produce effective pressure pulses over a very wide intensity range with a high degree of reproducibility.

The lifespan of the EMSE is of the order of one million pulses. An EMSE does not show progressive degradation in its output power but it needs to be exchanged on a regular basis when the insulating materials and metals have reached their endurance limits.

The plane acoustic pulse generated by the EMSE is focused by an acoustic lens. The choice of the diameter of the EMSE and the focal length of the lens define the aperture angle of the system. The wide dynamic range that is available for EMSE systems, together with the wide choice of aperture angles, provides a unique toolbox for the therapy head designer, serving the different needs of shock-wave field shaping in lithotripsy, in orthopedic shock-wave application, and in other emerging applications. An EMSE is easily incorporated into a multifunctional device. Newer EMSE designs provide treatment results comparable to or even better than the results with the unmodified Dornier HM3.

STORZ electromagnetic shock-wave source: cylinder source with parabolic reflector

The electromagnetic cylinder source was also developed to overcome some of the drawbacks of the powerful but unstable spark gap technology with a short electrode lifespan. The cylinder generator is based on a hollow electromagnetic cylinder composed of a cylindrical coil covered by an insulating membrane, which again is covered by an electrically conducting membrane of high strength. An intense pulse current with short rise time generates repelling pulse forces due to electromagnetic induction. When immersed in water, the radially expanding membrane generates, primarily, an acoustic cylinder wave which is focused by a special rotational parabolic reflector. This works on the same principle as a loudspeaker, but with very intense and short acoustic pulses.

The cylindrical coil/membrane configuration is very stable and delivers more than one million pulses without degradation or significant fluctuations of acoustic energy. The parabolic reflector can be designed with large apertures and, accordingly, large aperture angles without technical limitations. Due to the large aperture angle, the acoustic energy can be concentrated to laterally narrow and axially short focal zones with high peak pressure and high energy flux density values. Thus, the fragmentation shock-wave energy is restricted to a relatively small area, reducing tissue lesions in front or behind the target stone. Also, anesthesia requirements and shock-wave load affecting the coupling area at skin level are minimized. In contrast to the electrohydraulic spark gap technology, the energy level of each single shock-wave pulse can be precisely adjusted between very low (painless) and powerful settings, exactly matching the pain tolerance of the patient.

The generator configuration featuring a hollow cylinder provides sufficient space for favorable in-line localizations, either for fluoroscopic or ultrasonic targeting.

Piezoelectric shock-wave sources

Piezoelectric shock-wave generation was developed simultaneously by EDAP and Wolf [15–19]. The conversion of electric to acoustic energy takes place in ceramic platelets that expand or contract in the surrounding water because of the piezoelectric effect when a pulse of several thousand volts is applied. Several dozen to several thousand platelets are usually mounted on a spherical segment transmitting the shock wave into the center of the sphere through direct focusing. However, compared to other shock-wave sources, the intensity of a typical piezoelectric generator is lower and a large converter surface is required to mount the platelets. To provide sharp focusing of the acoustic pulse, the diameter of a piezoelectric source needs to be large. Consequently, the large diameter of a piezoelectric dish compromises its easy incorporation into a multifunctional device.

The piezoelectric shock-wave source of the Wolf Piezolith 3000 features a double layer of piezoceramic elements (double layer piezo-technology).

Each type of shock-wave source produces a shock-wave, i.e. an acoustic pulse of which the energy is focused towards and concentrated in the therapeutic focus. In an electrohydraulic lithoptripter the focusing is achieved by a semi-ellipsoid reflector, whereas in an electromagnetic lithotripter shock waves are focused using an acoustic lens or a parabolic reflector. In a piezoelectric system there is no focusing as such. Each ceramic crystal should be considered as a separate point source that produces its own miniature shock wave. The ceramic crystals are arranged on a dish that directs the point sources towards the therapeutic focus, where the accumulation of the energy from all these separate point sources produces sufficient energy for stone fragmentation [direct focusing lithotripsy (DFL)].

Introduction to shock-wave physics

A shock wave is an acoustic pulse characterized by a very fast rise time, a very high overpressure, a very short pulse duration, and a phase of underpressure.

The physics of shock waves is very complex [14], and a basic understanding of some of the parameters in shock-wave physics is useful.

Energy flux density in the focus.

The energy flux density (ED) is a measure of energy concentration:

$$\mathrm{ED} = \frac{\mathrm{Energy}}{\mathrm{Area}}$$

In focused shock-wave systems, the same total energy passes through a decreasing area as the wave travels towards the focal area. Thus the ED increases and reaches its maximum at the focus.

In extensive experiments, Loske found that ED correlates very well with stone fragmentation [20]. He also noted that the negative part of the shockwave (p–), supposedly mainly responsible for the cavitation effect, reaches its maximum below F2. As cavitation is deemed one of the main causes of shock-wave-related tissue damage, it is suggested that treatment outcomes may be improved by positioning the stone several millimeters below F2 (“prefocal alignment”).

Focus size

According to the International Electrotechnical Commission (IEC) standard 61846 (Ultrasonics/Pressure pulse lithotripters/Characteristics of Fields, International Electrotechnical Commission, Geneva, Switzerland), the focus size in one dimension is the width of the pressure curve where the pressure has decreased to half of the peak pressure. This is also referred to as the −6 dB focus, which is a measure relative to the peak pressure.

Effective energy

The effective energy (E_{12mm}) is a measure of the energy per shock wave that is transmitted through a circular area of 12 mm in diameter, representing a typical stone size of 12 mm. The calculation of the E_{12mm} is based on the integration of the ED over a circular area of 12-mm diameter. The E_{12mm} provides good correlation with the disintegration capacity of a lithotripter. Comparison of different lithotripters remains difficult, however.

Effect of the aperture angle

For the same E_{12mm} delivered into the focus, a shock-wave source with a larger aperture angle will have a smaller −6 dB focus, a sharper focus with higher pressure, and a higher focal ED, whereas a shock-wave source with a smaller aperture angle will be characterized by a larger −6 dB focus, a less sharp focus with lower pressure and a lower focal ED.

Maximum treatment depth

The maximum treatment depth is the distance between the shock-wave head and the point of highest pressure in front of this. This is the geometric focus. The shock-wave focus however is cigar shaped, with the axial dimension longer than the lateral. This means that there is still energy that may be sufficient to break a stone beyond the geometric focus. This is referred to as the "blast path."

In their published specifications, some manufacturers may "extend" their treatment depth by also incorporating the blast path, thus adding half of the focal length to the geometric focus and "stealing" some distance.

Clinical relevance of focus size

There is an ongoing debate about the ideal focus size in a lithotripter [21, 22]. The ideal focus would be a spherical volume exactly matching the size of the targeted stone, thus limiting the administration of energy to the stone and avoiding hitting the surrounding tissue, leading to adverse tissue effects [21, 22]. However, this is technically not feasible. Today's lithotripters have a cigar-shaped focus with energy delivered in front, behind (blast path), and adjacent to the target.

A small focus is highly confined and sharp. The higher pressure in a small focus leads to high efficiency in fragmenting hard stones. In order to obtain optimal fragmentation and to avoid adverse tissue effects, precise targeting is essential.

In a large focus, pressure is lower. Precise targeting is less critical but there is an increased analgesia need and a higher risk of adverse tissue effects. Sometimes there is a demand for larger focal zones in order to treat larger target volumes, even if surrounding tissue may be affected more than technically necessary. To respond to this demand Storz introduced the dual focus technology. The design of the electromagnetic cylinder source offers the possibility to select different focal zones, precise and extended, according to clinical and anatomic conditions. By modification of the electrical excitation of the coil, longer pulses may be generated, which, in turn, stretch the focal zone, both laterally and axially.

The Wolf Piezolith 3000 features a triple focus: F1 = small focus with high ED; F2 = intermediate focus with medium-to-high ED; and F3 = larger focus with medium ED.

Prospective trials to investigate the potential clinical benefits of selectable foci would be useful.

Shock-wave interaction mechanisms

It is generally assumed that a combination of four different mechanisms is involved in the interaction between shock waves and the targeted stone: Hopkinson effect, cavitation, quasistatic squeezing, and dynamic fatigue [10]. It is also assumed, that cavitation and shear forces (Hopkinson effect) are the main culprits in the origin of adverse tissue effects. Although both shear forces and cavitation are also important in the stone comminution process, avoidance of their negative effects is considered important in reducing adverse effects due to shock waves.

The idea behind a dual pulse technique [23, 24] is to "fill" the negative part of the pressure pulse with a positive pressure pulse. In the Direx Duet, dual shock-wave sources are used. Fired synchronized or asynchronized they allow an increase in the total pressure and the shock-wave rate. Sheir *et al*. [23] demonstrated improved stone comminution with a synchronized discharge of a twin pulse. In another study by the same group higher performance and efficacy with this twin-head, twin-pulse technique was demonstrated [24]. At the same time, this technique produced far less parenchymal damage than with the use of a single treatment head. Theoretically, this would reduce cavitation and improve disintegration.

Eisenmenger advocates the use of a wide focus with lower pressure to enhance quasistatic squeezing, as this will presumably reduce tissue trauma and improve disintegration [25–27]. This low pressure–wide focus technology is incorporated in the Lithospace (Advanced Shockwave Technology GmbH, Germany).

Coupling

As already mentioned, shock waves are acoustic waves that travel through a medium by alternating decompression and compression of the medium. Absorption, reflection or refraction of the shock waves can occur at interfaces between media with different acoustic impedance.

As water has comparable acoustic properties to human tissue, shock waves are generated and transmitted in water. In order to minimize energy loss of the shock wave at the interface between the patient and the shock wave source, coupling between shock wave source and patient is extremely important [27].

Total immersion of the patient in a water bath with degassed water where the shock wave is generated (Dornier HM3) is still considered the ideal coupling system. Second- and third-generation lithotripters, however, feature a "dry" coupling, which consists of a water-filled cushion that is inflated and pressed against the patient. The water cushion is made of elastic PVC or silicone, and is capable of adapting to the body contour of the patient. In order to guarantee good acoustic transmission, the water cushion is coupled to the patient through the application of ultrasound gel. In this process, both air bubbles in the coupling gel and folds in the water cushion could impair the transmission of acoustic waves. Even tiny air bubbles in this interface can lead to uncontrolled shock-wave attenuation. In an *in vitro* experiment, Pishchalnikov *et al.* [28] found a 20–40% reduction in fragmentation when air bubbles covered an area equal to 2% of the cushion surface [28]. Decoupling the cushion from the test basin and recoupling it led to a drastic increase in air inclusions. This has led to the recommendation that, if the patient is decoupled during treatment, the coupling procedure must be repeated, including cleansing the coupling cushion and subsequently reapplying gel.

Based on their own stone model, Jain *et al*. were able to identify a considerable influence of air inclusions on the erosion capacity of the shock wave [29]. After experimenting with various techniques for gel application, as a method of choice Neucks *et al.* [30] recommend applying the gel as a bolus, specifically from a vessel with a large opening. A small vessel opening and manual distribution of the gel lead to increased air pockets and poor disintegration results. Bergsdorf *et al*. also recommend the selection of a proper coupling gel disc or gel with low viscosity and the accurate removal of air bubbles to improve efficiency in SWL [31].

Imaging systems

Adequate imaging is vital to the success of ESWL:

- Localization and targeting of the stone;
- Surveillance of treatment progress;
- Identification of fragmentation.

Imaging modalities available on a lithotripter will also to a great extent define treatment strategies.

Early lithotripters were equipped either with ultrasound or fluoroscopy (X-ray). In order to meet all the challenges in modern integrated stone management, current lithotripters should ideally be equipped with both imaging modalities to be used either independently and alternately, or simultaneously. Online use of both modalities is essential.

Fluoroscopy allows targeting of radio-opaque stones at all levels of the urinary tract. Direct targeting of radiolucent stones is impossible, however. Also, smaller renal stones may prove more difficult to locate than with ultrasound. Further drawbacks are the absence of real-time imaging and the exposure to radiation.

With ultrasound it is generally impossible to locate stones in the major part of the ureter, but it allows direct visualization of radiolucent stones and offers easier targeting of smaller renal stones. Its major advantage, however, is realtime imaging, which provides better monitoring of the fragmentation process in the absence of exposure to radiation.

Machines where both ultrasound and X-ray are integrated offer the most versatile imaging and targeting possibilities. Ideally, these machines offer simultaneous online use of both ultrasound and X-ray. Targeting versatility is further improved by the possibility to couple the therapy head to the patient both under and above the treatment table.

Improved imaging and improved targeting will have a positive effect on the effectiveness quotient (EQ).

Lithotripter design

Dedicated or multifunctional machine?

In the first years following its introduction, ESWL was the privilege of high-volume stone centers. This was mainly due to the high costs of the first lithotripters: high capital, running, and maintenance costs. As they were "dedicated" to SWL, these machines were only operated in large centers with a high volume of stone patients.

The construction of less expensive second- and third-generation lithotripters with lower capital, running, and maintenance costs made ESWL available in more and more centers, leading to a reduction in the number of patients treated per stone center.

Stone therapy guidelines from international expert boards consider ESWL to be the first-choice treatment for most types of stones. However, in some indications, endourologic procedures give equivalent or better results as compared to ESWL. In modern stone management, ESWL and endourology are complementary. Lithotripters should ideally support the urologists in any of these modalities. Consequently, in the past two decades lithotripters have undergone a transition from pure shock-wave generating devices to multifunctional urologic workstations.

One of the key components of such urologic workstations is the patient table. An increasing number of obese patients require high load capacity tables with maximum accessibility in order to be able to approach them from all sides. For fluoroscopic imaging both in ESWL and endourologic procedures, the tabletop needs to be radiotransparent.

Imaging modalities in a multifunctional workstation need to support the wide range of therapeutic options in urology. Large image intensifiers of up to 16 inches ideally offer a large field of view of nearly the entire urinary tract. Full digitization of the X-ray imaging chain provides excellent image quality at low radiation dose. Increasing awareness of radiation safety and dose reduction make ultrasound stone localization an ideal tool for stone targeting and accurate therapy monitoring. Last but not least, a high performance shock-wave source, which ideally can be coupled to the patient in an over- and under-table position, completes the design of a multifunctional lithotripter.

Integrated or modular?

Multifunctional machines can have a modular design, where all components are separate modules to be “connected” according to need, or an integrated design where all components are integrated in the machine and ideally adapted to their function. A third design, the “hybrid”, offers integration of imaging and/or therapy head in a common console with a detached treatment table.

Modular design

In a lithotripter with a modular design (Figures 50.1 and 50.2) the shock-wave source, imaging components, and treatment table are separate modules that need to be connected to perform ESWL or endourologic procedures.

As the imaging components, a fluoroscopic C-arm and an ultrasound machine, usually are available on site, investment cost is limited to the shock-wave module and the treatment table. The imaging components can also be used for other purposes, both in urology and other departments. Modular systems have no need for a dedicated lithotripsy room and are easily transported from one center to another.

Due to the combination *ad hoc* of different modules, the footprint is larger and the floor is cluttered with an array of machinery. In endourologic procedures, this footprint is further enlarged by the addition of an electrosurgical unit, light sources, and monitors, etc. The uro-table is less urologist friendly with limited accessibility, and overall handling is more complicated.

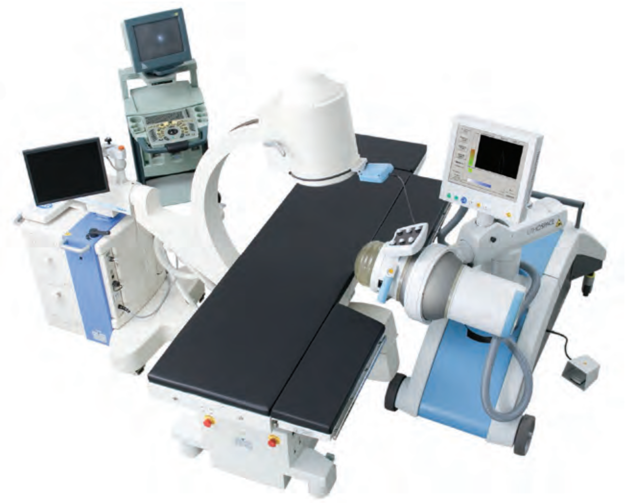

Figure 50.1 Modular design: AST Lithospace (reproduced courtesy of Advanced Shockwave Technology GmbH).

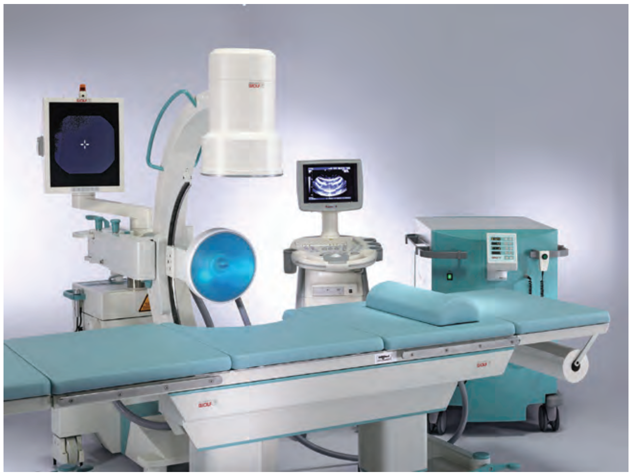

Figure 50.2 Modular design: Wolf Piezolith 3000 (reproduced courtesy of Richard Wolf GmbH).

Integrated design

In an integrated design, the different components, shock-wave source, imaging, and treatment table, are fully integrated in one stand-alone system (Figures 50.3–50.5). These systems have a small footprint compared to the modular and hybrid designs. Due to the optimal integration and synchronization of their high end components to form a synergistic system, these machines offer maximal versatility in targeting and positioning for ESWL. Uro-table function usually is excellent and offers great comfort in the performance of endourologic procedures. Ideally this patient table is

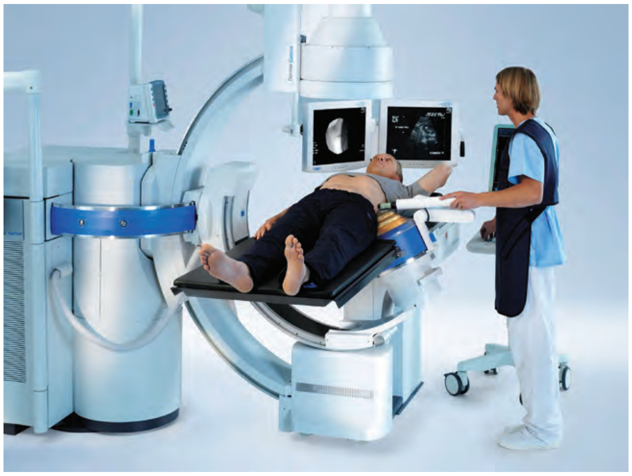

Figure 50.3 Integrated design: Dornier Gemini (reproduced courtesy of Dornier MedTech GmbH).

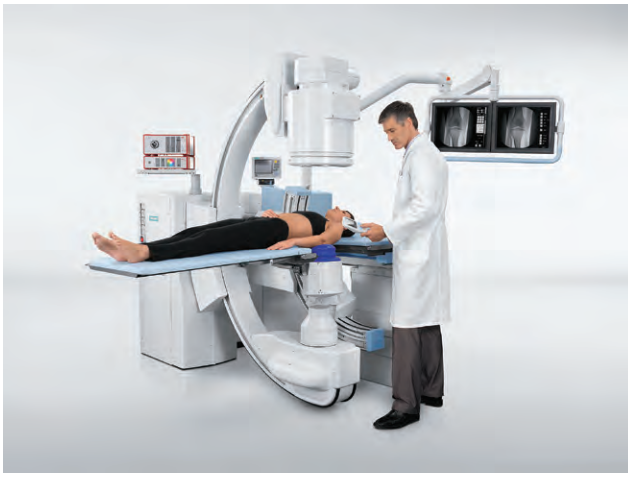

Figure 50.4 Integrated design: Siemens Lithoskop (reproduced courtesy of Siemens AG).

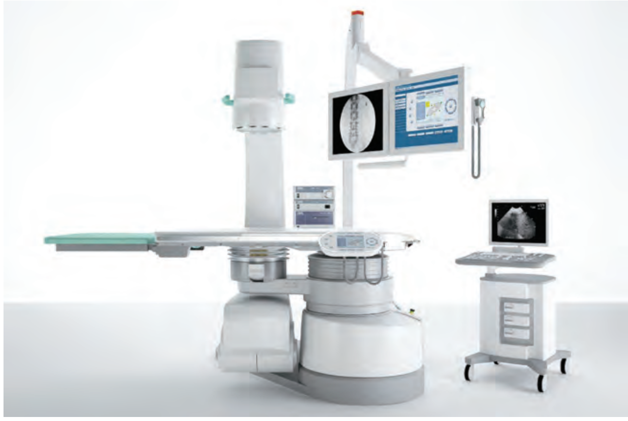

Figure 50.5 Integrated design: Storz Modulith SLX-F2 (reproduced courtesy of Storz Medical AG).

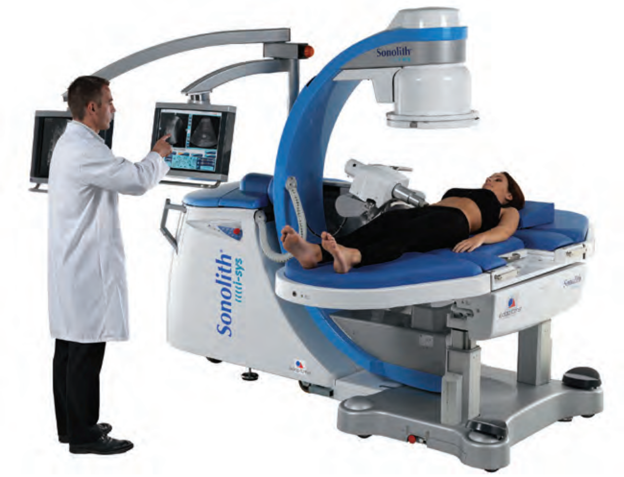

Figure 50.6 Hybrid design: EDAP TMS Sonolith i-Sys (reproduced courtesy of EDAP TMS GmbH).

entirely radiotransparent, accessible over 360°, and able to bear obese patients.

The higher investment cost and the fixed installation in a dedicated endourology/ESWL room may prohibit its acquisition by centers with limited patient loads.

Hybrid design

In these machines imaging (fluoroscopy and/or ultrasound) and shock-wave source are mounted on a combined console (Figure 50.6). The patient treatment table is a stand-alone component to be added to the system for ESWL or endourologic procedures. Both investment cost and footprint are between that for a machine with an integrated design and a device with a modular design. These systems are easily transportable and do not need a dedicated room. Some of the components (imaging, patient table) are suited for multifunctional and multidisciplinary usage. Uro-table function usually is adequate and overall ease of handling is between that for the modular and integrated designs.

Performance of lithotripters

To measure the performance of a lithotripter, formulas have been devised that take into account stone-free rate, retreatment rate, and auxiliary procedure rate.

The original effectiveness quotient (EQ_A) was defined by Denstedt *et al.* [10, 32]:

$$EQ_A = \frac{\%\ \text{Stone-free patients}}{100\% + \%\ \text{retreatment} + \%\ \text{auxillary procedures post-ESWL}} \times 100$$

The "extended EQ" or EQ_B [10] and the "modified EQ" or EQ_{mod} [10] were defined in order to fine tune the performance estimations:

$$EQ_B = \frac{\%\ \text{Stone-free patients}}{\begin{array}{l}100\% + \%\ \text{retreatment}\\ + \%\ \text{auxillary procedures}\\ \quad\text{pre- and post-ESWL}\end{array}} \times 100$$

$$EQ_{mod} = \frac{\begin{array}{l}\%\ \text{Stone-free patients} -\\ \%\ \text{curative auxillary procedures}\end{array}}{\begin{array}{l}100\% + \%\ \text{re-ESWL}\\ + \%\ \text{pre-ESWL auxillary procedures}\\ + \%\ \text{post-ESWL auxillary procedures}\end{array}} \times 100$$

Although these formulas represent a mathematic tool to quantify and compare the performance of lithotripters, they only quantify stone-free rate, auxiliary procedure rate, and retreatment rate. A number of other factors are not readily quantifiable, but do play an important role in the final outcome of stone management by SWL: Shock-wave source, stone burden, stone impaction, imaging modality and quality, targeting, analgesia regimen, shock-wave coupling, shock-wave release frequency, treatment strategy, and experience of the operator. Treatment strategies and the experience and skill of the operator have long been underestimated in the performance of ESWL. Operator skill and experience unquestionably are key factors in success.

Although newer electromagnetic machines perform at least as well or even better than the HM3 (Table 50.1), the unmodified Dornier HM3 is still considered the "gold standard" in ESWL. Results with newer lithotripters are, often erroneously, claimed to be poorer than with the original HM3, and many urologists therefore tend to distrust ESWL in a number of indications.

Factors in the poorer results with modern lithotripters without a doubt are:

- Complexity of shock-wave administration is generally underestimated, especially by new users: lack of background and training in ESWL is often the cause of poorer results with modern machines;
- HM3 users were extensively trained prior to certification;
- Newer machines are too often misjudged as "plug-and-play," with little attention paid to proper training of new users.

In order to improve results and reduce complication rate, all (new) users of shock-wave machines should be certified on the basis of:

- A theoretical understanding of the basic physics of shock waves;
- An extensive training in imaging, positioning and targeting, coupling, and treatment strategies;
- A comprehensive understanding of shock-wave complications and the ways to avoid them and improve results.

Although lithotripter manufactures are directing extensive research towards improvements in focal geometry and energy to improve stone disintegration and at the same to reduce collateral damage to the surrounding tissue, together with urology teaching institutions they should also invest in proper training of lithotripter users.

Table 50.1 Range of extended EQ (EQ_B) for Dornier HM3, electrohydraulic, electromagnetic and piezoelectric machines.

	Range	References
Dornier HM3 (unmodified)	25–67	33–44
Electrohydraulic machines	25–67	36, 43, 45–61
Electromagnetic machines	31–80	50, 54, 62–72
Piezoelectric machines	30–64	47, 50, 60, 73–79

The ideal lithotripter and conclusions

An "ideal" lithotripter would have a high performance shock-wave source producing a spherical focus exactly matching the size of the targeted stone, and with the following energy requirements:

- Moderate peak pressure;
- Sufficient disintegration power (ED and E_{12mm}) to disintegrate hard stones and to compensate for shock-wave attenuation (obesity);
- Minimal cavitation effects and hence minimal risk of adverse tissue effects.

Apart from producing a shock wave with the ideal focus, this high-performance shock-wave source would also meet the following requirements: prolonged lifetime without degradation or significant fluctuations of acoustic energy; wide range of energy settings; adequate treatment depth (minimum 150 mm) to accommodate the ever increasing proportion of obese patients, and be easily incorporated in a multifunctional device. These requirements almost automatically exclude conventional electrohydraulic sources: the lifetime of their electrodes is limited and the degradation of the electrode tips leads to output variations and instabilities of focal point and energy.

Coupling of the therapy head containing the shock-wave source is an important issue. The water cushion needs to be made of a material that easily adapts to the body curves and that causes minimal absorption, reflection or refraction of the traveling shockwave. Also, the ability to couple the treatment head to the patient both in an above- and an under-table position

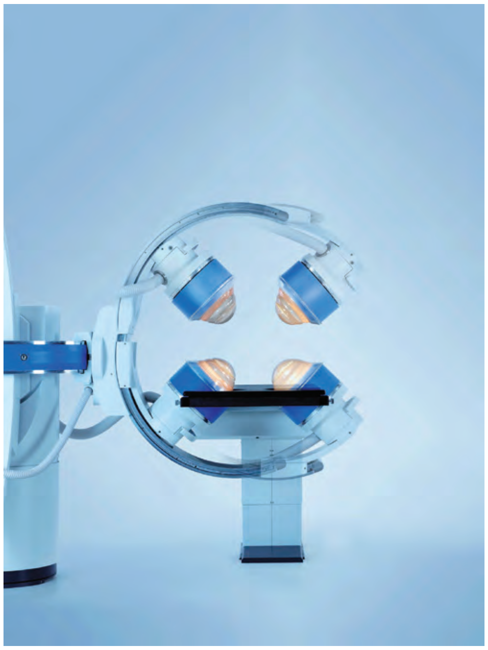

Figure 50.7 Bilateral over- and under-table position of the therapy head (Dornier Gemini) (reproduced courtesy of Dorner MedTech GmbH).

(Figure 50.7) is a very important asset, specifically in the *in situ* treatment of ureteral stones and especially in obese patients.

Accurate targeting is key to success in SWL and depends on excellent image quality, both fluoroscopic and ultrasonic. In endourologic procedures, image quality is equally important. A large image intensifier (up to 16-inch) offers a large view of nearly the entire urinary tract without the need to move the patient table. Orbital isocentric movements of the X-ray C-arm may prove useful both in SWL and endourology. Full digitization of the X-ray imaging chain guarantees excellent image quality at low radiation dose and allows easy and efficient storage of the images in the patient's records (DICOM capability).

Increasing awareness of radiation safety and dose reduction and the excellent image quality of modern ultrasound machines make ultrasound stone localization an ideal tool for stone targeting and realtime monitoring of the entire treatment. An ideal lithotripter thus should be equipped with excellent imaging, both fluoroscopic and ultrasonic, preferably to be used online and simultaneously.

Another key component of a modern multifunctional lithotripter is the patient table. An ever increasing number of obese and even morbidly obese patients demands a high load capacity of the treatment table. To allow good imaging, the table top needs to be radiotransparent. Finally, in endourologic procedures, such as PCNL, nephrostomy tube placement, etc., maximum accessibility (ideally 360°) of the table from all sides is extremely important.

Good imaging and a careful urologist may provide accurate targeting, but respiratory movements continuously swing the targeted stone in and out of the focus. A hit-and-miss system that keeps track of the stone during respiratory movements and only releases a shock wave when the stone is exactly in the focus would improve outcome and reduce collateral damage to the surrounding tissue. It would of course also slow down treatments. According to newer insights, however, slowing down treatments not only improves treatment efficiency [80, 81], but also reduces overall treatment cost [82].

Finally, this sophisticated piece of equipment should only be operated by an interested and experienced urologist, who has a basic understanding of the physics of shock waves [14, 27] and who is closely involved in all treatment modalities (ESWL, PCNL, URS, retrograde intrarenal surgery) of modern stone management.

A department of urology looking for the ideal lithotripter should therefore also invest in good clinical practice and "good lithotripsy" (Figure 50.8). The actual choice of the ideal lithotripter for any given stone center will depend on the specific requirements of a specific setting. Few centers probably have the high patient load for SWL to justify the acquisition of a dedicated lithotripter. A multifunctional workstation for SWL and endourologic procedures is the best choice for centers with an adequate patient load in both treatment modalities. An integrated or hybrid design makes economic sense in very active stone centers. In centers with a modest patient load, a modular system is probably the better choice.

Our own stone center functions 5 days/week with a patient load of approximately 3000 treatments per year (± 600 ESWL and ± 2400 endourologic procedures). We try to solve any acute stone problem within 24 h of admission, preferably on an outpatient basis. The centerpiece of this "integrated endourology concept" is a high-end multifunctional lithotripter with integrated design.

The number of manufacturers and machines currently on the market prohibits any attempt to provide a complete overview of all systems available at present. Also, companies and machines come and go. Therefore, this overview (Tables 50.2–50.7) is limited to those traditional companies who were and are very much involved in the development of and the continued research in SWL. An exception to this rule was made for the AST Lithospace, a lithotripter designed with a philosophy derived from the theories of Eisenmenger [25, 26]: large focus, low focal pressure.

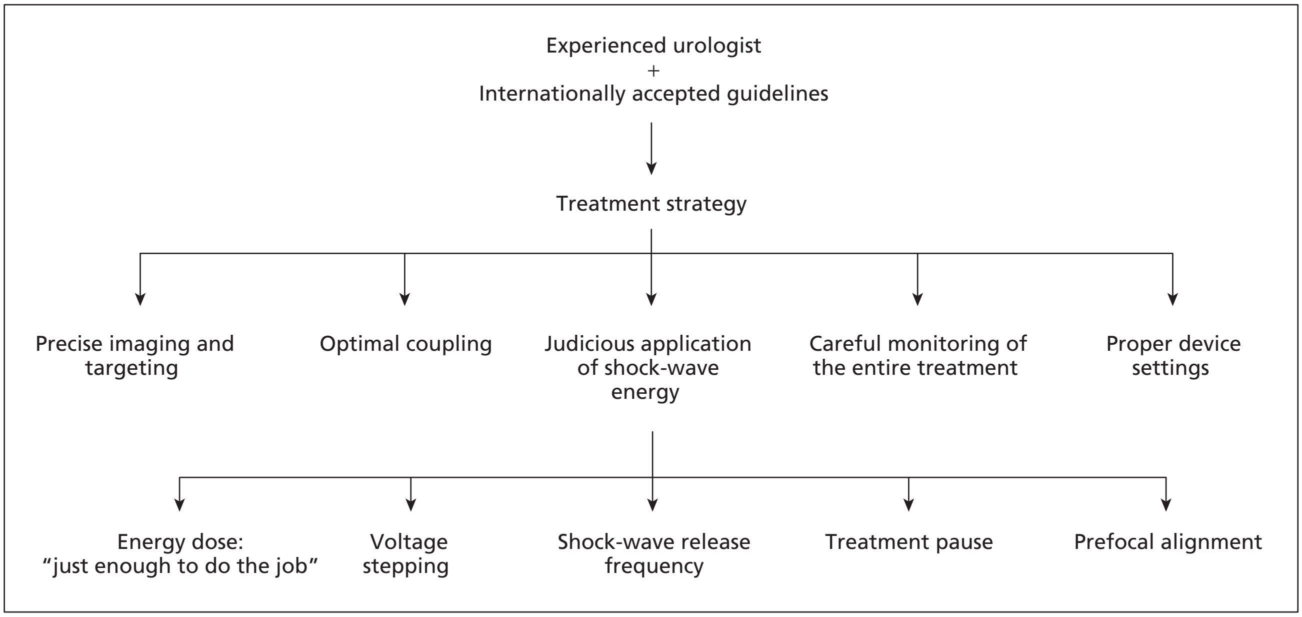
Experienced urologist
+
Internationally accepted guidelines
Treatment strategy
Precise imaging and targeting
Optimal coupling
Judicious application of shock-wave energy
Careful monitoring of the entire treatment
Proper device settings
Energy dose: "just enough to do the job"
Voltage stepping
Shock-wave release frequency
Treatment pause
Prefocal alignment

Figure 50.8 Elements of "good lithotripsy."

Table 50.2 Overview of the AST Lithospace lithotripter.

Shock-wave generation			
• Type of SW-Source	Electrohydraulic		
• Aperture (mm)	178		
(degrees)	45.6 (210 mm)–58.3 (160 mm)–96.1 (80 mm)		
• Max treatment depth (mm)	180 (16 kV)/205 (22 kV)/220 (26 kV)		
• Power settings	16–26 kV in 1-kV steps		
• Focus:	16 kV	22 kV	26 kV
– Focus size (–6 dB) in mm	10 × 64	12 × 125	20 × 160
– Peak pressure (MPa)	–3.6–26.1	–4.1–35.2	–5.0–37.9
– ED (mJ/mm^2)	0.14	0.27	0.40
Coupling	Water cushion		
Imaging			
• Fluoroscopy	Add-on C-arm		
• Ultrasound	Add-on US-machine		
Overall design	Modular		
Anesthesia	Anesthesia free: IV analgosedation		
Multifunctional use	Add-on uro-table		
Special features	Flexibility and maneuverability of shock-wave head: under- and over-table Autonomous contact-free targeting system for all X-ray and ultrasound localization devices Stone localization and treatment volume superimposed in realtime on the display Multiuse electrode: RevoTrode for 15 000 shock waves		

Table 50.3 (A) Overview of the Dornier lithotripters Dornier Gemini and Dornier Lithotripter S II.

	Dornier Gemini	Dornier Lithotripter S II
Shock-wave generation	Electromagnetic (EMSE)	Electromagnetic (EMSE)
• Type of shock-wave source	Flat coil with acoustic lens	Flat coil with acoustic lens
• Aperture (mm)	220	220
(degrees)	66	73
• Max treatment depth (mm)	150/170 optional	150
• Power settings	Levels 1–15	Levels 1–15
• Focus (max values):		
– Focus size (–6 dB) in mm	5.4 × 63	5.4 × 63
– Peak pressure (MPa)	90	90
– ED (mJ/mm^2)	1.9	1.9
Coupling	Water cushion	Water cushion
Imaging		
• Fluoroscopy	Integrated C–C and orbital movements	Integrated C–C movements
• Ultrasound	Integrated Lateral isocentric	Integrated Lateral isocentric
Overall design	Integrated	Integrated
5. Anesthesia	Anesthesia free	Anesthesia free
6. Multifunctional use	+++	+++
7. Special features	Patient table : • Load capacity = 250 kg • 360° accessibility • Radiotransparent carbon-fiber top	
	Dual imaging: simultaneous online use of X-ray and ultrasound	Dual imaging: simultaneous online use of X-ray and ultrasound
	Satellite arms for flat screens, light source, electrosurgical unit	
	Bilateral shock-wave coupling over- and under- table	
	UIMS (Urology Information Management System)	UIMS: Urology Information Management System
	16-inch image intensifier/DICOM capability	DICOM capability
	Autopositioning	Autopositioning

Table 50.3 (B) Overview of Dornier Compact Delta II and Compact Sigma.

	Dornier Compact Delta II	Dornier Compact Sigma
Shock-wave generation	Electromagnetic (EMSE)	Electromagnetic (EMSE)
• Type of SW-Source	Flat coil with acoustic lens	Flat coil with acoustic lens
• Aperture (mm)	140	140
(degrees)	50	50
• Max treatment Depth (mm)	150	150
• Power settings	9 steps	9 steps
• Focus (max values):		
– Focus size (–6 dB)	8 × 105 mm	8 × 105 mm
– Peak pressure (MPa)	51	51
– ED (mJ/mm^2)	0.88	0.88
Coupling	Water cushion	Water cushion
Imaging		
• Fluoroscopy	Integrated C-arm	Add-on C-arm
• Ultrasound	Integrated Lateral isocentric	Integrated Lateral isocentric
Overall design	Hybrid	Modular
Anesthesia	Anesthesia free	Anesthesia free
Multifunctional use	With Relax Plus table	With Relax Plus table
Special features	Tri-mode imaging capability (with FarSight) FarSight Imaging capability with purpose-designed transducer Simultaneous online use of X-ray and ultrasound Optional: UIMS Optional: DICOM capability Over- and under-table treatment Multidisciplinary use of Relax Plus table	

Table 50.4 Overview of Siemens lithotripters.

	Siemens Lithoskop	Siemens Modularis Variostar	Siemens Lithostar Modularis Vario
Shock-wave generation	Electromagnetic	Electromagnetic	Electromagnetic
• Type of shock-wave source	Flat coil with acoustic lens	Flat coil with acoustic lens	Flat coil with acoustic lens
• Aperture	Not disclosed	Not disclosed	Not disclosed
• Max treatment depth (mm)	160	140	140
• Power settings	38 steps	38 steps	38 steps
• Focus	Data not disclosed	Data not disclosed	Data not disclosed
Coupling	Water cushion	Water cushion	Water cushion
Imaging			
• Fluoroscopy	In-line	Add-on	Add-on
• Ultrasound	In-line	Add-on	Add-on (lateral)
Overall design	Integrated	Modular	Modular
Anesthesia	Anesthesia free	Anesthesia free	Anesthesia free
Multifunctional use	Yes	Yes	Yes
Special features	Yes	No	No
Autopositioning			

Table 50.5 Overview of Storz lithotripters.

	STORZ Modulith SLX-F2	STORZ Modulith SLK
Shock-wave generation	Electromagnetic	Electromagnetic
• Type of SW-Source	Cylinder source with parabolic reflector	Cylinder source with parabolic reflector
• Aperture (mm)	300	178
(degrees)	84.5 (165-mm focus depth) 80.0 (180-mm focus depth)	61
• Max treatment depth (mm)	165/180 optional	150
• Power settings	26	26
• Focus:		
– Focus size (–6 dB) in mm	Precise: 6 × 28 Extended: 9 × 50	4 × 50
– Peak pressure (MPa)	Precise: 5–150 Extended: 5–90	6–120
– ED (mJ/mm^2)	Precise: 0.03–3.65 Extended: 0.03–2.4	0.04–2.0
Coupling	Water cushion	Water cushion
Imaging		
• Fluoroscopy	Integrated Add-on C-arm optional	Add-on C-arm
• Ultrasound	In-line	In-line
Overall design	Integrated Hybrid: with add-on C-arm (optional)	Modular
Anesthesia	Anesthesia free	Anesthesia free
Multifunctional use	Multifunctional table including Trendelenburg	Multifunctional table including Trendelenburg
Special features	Autopositioning	Therapy head on articulated arm for variation of coupling directions
	Dual focus: precise and extended	
	StormTouch: centralized control station for lithotripsy and endourology equipment	Lithotrack: unique tracking system for 3D positioning of therapy head
	StormBase: lithotripsy databank	Local and remote operation with attachable motor drive for Philips C-arms
	Local and remote control operation	
	Optional: dual monitor arm with touchscreen control	Extreme flexibility for ultrasound localization

Table 50.6 Overview of EDAP TMS lithotripters.

	EDAP TMS Sonolith i-Sys	EDAP TMS Sonolith Praktis
Shock-wave generation		
• Type of SW-Source	Electroconductive (ECL)	Electroconductive (ECL)
• Aperture (mm)	291	219
(degrees)	80	80
• Max treatment depth (mm)	130	170
• Power settings	100	21
• Focus		
– Focus size (–6 dB) in mm	3.2 × 2.6 × 22.4	3.1 × 2.2 × 26.8
– Peak pressure (MPa)	129	124
– ED (mJ/mm^2)	1.27	1.16
Coupling	Water cushion	Water cushion
Imaging		
• Fluoroscopy	Integrated	Add-on C-arm
• Ultrasound	Outline (motorized)	Outline (manual)
Overall design	Hybrid	Modular
Anesthesia	Anesthesia free	Anesthesia free
Multifunctional use	Yes	Yes
Special features		
• Automatic pressure regulator	Yes	Yes
• Autopositioning: "Stone Locking System"	Yes	No
• Fully robotized automatic ultrasound positioning system	Yes	No
• Fully robotized and motorized isocentric movements of X-ray C-arm, ultrasound and shock-wave generator	Yes	No
• Dual X-Ray and ultrasound display	Yes	Yes
• Touchscreen interface	Yes	No
• Simultaneous imaging and SW-release	Yes	Yes

Table 50.7 Overview of the WOLF Piezolith 3000.

Shock-wave generation	
• Type of shock-wave source	Piezoelectric: Double Layer Piezo-technology
• Aperture (mm)	270
(degrees)	74
• Max treatment depth (mm)	165
• Power settings	20 intensity settings
• Focus	Triple focus
– Focus size (–6 dB) in mm	3 × 16/5 × 24/8 × 28
– Peak pressure (MPa)	6–126
– ED (mJ/mm^2)	0.03–1.67
Coupling	Water cushion
Imaging	
• Fluoroscopy	Outline X-Ray with LithoArm
• Ultrasound	In-line ultrasound
Overall design	Modular
Anesthesia	Anesthesia and sedation free
Multifunctional use	Add-on uro-table
Special features	Long-lastie: >>5 000 000 shocks Triple focus: three focus sizes LithoArm for outline X-ray Autopositioning not available

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CHAPTER 51

Shock-Wave Treatment of Renal Calculi

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Introduction

Several factors can decide the need for active removal of kidney stones. Pain is the most common reason; either frequent episodes of colic or a constant or intermittent dull ache. Occasionally, hematuria is a symptom that precedes the diagnosis and stone removal is often the only way to eliminate the bleeding. Stone material may harbor bacteria, causing constant bacteriuria or intermittent and frequent episodes of urinary tract infection (UTI). Repeated episodes of obstruction, with or without UTI, can lead to reduced renal function. In addition, renal stones also qualify for removal as a prophylactic step when their size makes spontaneous passage unlikely.

In as much as renal stone formation is associated with a high recurrence risk, it is logical to choose a method that is as effective, minimally invasive, and gentle as possible. Today, extracorporeal shock-wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), retrograde intrarenal surgery (RIRS), and laparoscopic surgery are all minimally invasive techniques, but they do have varying degrees of invasiveness and different advantages and disadvantages.

In this chapter, important aspects of ESWL for treating patients with kidney stones will be discussed. It needs to be emphasized that with the introduction of non- and low-invasive methods, the indications for active stone removal have changed, and accordingly many patients are today treated for stones that previously, when open surgery was the only available method, were left for conservative surveillance and follow-up.

ESWL was introduced in 1980 [1] and was adopted worldwide in 1984. It has become the primary and dominant procedure for treating patients with kidney stones. Based on the experience from several millions of treated patients, this method, undoubtedly, has stood the test of time, but all medical procedures have both advantages and disadvantages and ESWL is no exception. Although both a certain fraction of patients may need more than one ESWL treatment session for an adequate disintegration of kidney stones, and residual fragments are encountered in a substantial number of patients, are matters of concern, the advantages are obvious. ESWL is a noninvasive or extremely low-invasive treatment that, in most patients, can be carried out without general or regional anesthesia on an outpatient basis [2]. Experience has shown that 90–95% of all stones can be satisfactorily disintegrated with ESWL [3]. If this goal cannot be achieved, there are essentially two factors that should be incriminated; first, that the function of the lithotripter is suboptimal [4–8] and second, and in many cases probably more importantly, that insufficient attention has been paid by the operator to various details of the treatment procedure.

In this chapter we consider how the results of ESWL of renal stones can be optimized, while simultaneously taking the necessary steps to avoid complications. The various highlighted issues come partly from our own personal experience of more than 20000 ESWL sessions carried out with various lithotripters during the past 25

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years, and partly from the numerous experimental and clinical reports in the literature during the same period of time.

Description of the stone problem

Of those patients with urinary tract calculi who require or fulfil indications for active stone removal, just over 50% present with kidney stones. It has been estimated that, at least in northern Europe and the USA, the annual incidence of stone disease is between 1500 and 2000 per million population [9, 10]. Moreover, at least 30% of these patients are candidates for active stone removal. This means that at least 250–300 patients per million population need to be considered for stone removal from the kidneys.

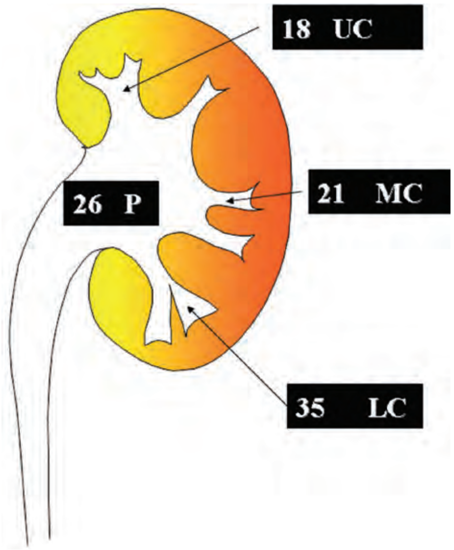

Figure 51.1 Percentage distribution of renal stones in the upper calyx (UC), middle calyx (MC), lower calyx (LC), and renal pelvis (P) recorded in a large unselected group of patients referred for active stone removal.

These stones have different sizes and chemical composition. The intrarenal location of stones recorded in an unselected group of stone formers, who were referred for stone removal in our department, is shown in Figure 51.1. Stone size is most often expressed in terms of the largest stone diameter, but this measure is too approximate and stone surface area (SA) is a better estimate, calculated from the largest diameter (*l*) and the width (*w*) of the stone [11, 12] (Figure 51.2).

$$\mathrm{SA} = l \cdot w \cdot \pi \cdot 0.25$$

Today, when computed tomography (CT) examinations are more commonly used, an estimate of the stone volume (SV) can be made from the length (*l*), width (*w*), and depth (*d*):

$$\mathrm{SV} = l \cdot w \cdot d \cdot \pi \cdot 0.17$$

Such measurements are, however, not commonly reported in the literature.

The dominant chemical stone constituents are shown in Table 51.1. In addition, mixtures of these stone

Table 51.1 Approximate average occurrence of chemical constituents of stones removed from a Swedish population of stone formers.

Main stone constituent	Percentage
Calcium oxalate	60
Calcium oxalate + calcium phosphate	20
Calcium phosphate	5
Infection stone	10
Uric acid	4
Cystine	1

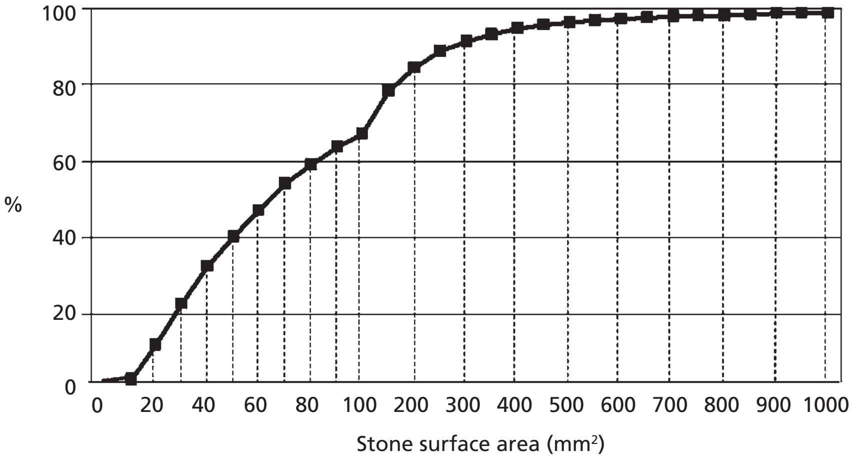

Figure 51.2 Cumulative frequency distribution of stone size expressed in terms of stone surface area. The data were obtained from the same group of patients as in Figure 51.1.

components as well as other unusual crystal phases can be encountered. Although considerable worldwide variations undoubtedly occur in all these variables, the treatment problems and strategic considerations are reasonably similar.

To predict the outcome of ESWL of renal stones and the efforts that may be required to solve particular problems, an understanding of the prerequisites in terms of stone size, stone composition, and stone location is important. Moreover, it is essential to pay due attention to the patient's anatomic and medical condition, as well as to any ongoing pharmacologic treatment.

Disintegration of stones

It is important not to confuse stone disintegration and stone-free rate. Whereas the first variable depends on the lithotripsy efficiency for a particular stone burden, the second is a function of lithotripsy efficacy and fragment elimination properties.

The basic prerequisite for a successful outcome of ESWL is to hit the kidney stone or stones with a sufficient disintegrating energy so that they break into small pieces. Different stones need different levels of energy. Needless to say, a lithotripter must provide sufficient shock-wave power for this purpose. The properties of different lithotripters are discussed in Chapter 50. Production of the Dornier Human Model 3 (HM3) lithotripter stopped in 1986, but it remained the "gold standard" for a considerable period of time, and few later lithotripters have shown similar capacity [5–8]. Why were the results with the original equipment superior for such a long period? A definitive explanation has not been provided, but the original HM3 device differed from modern lithotripters in several aspects and these are important considerations in understanding how optimum results can be obtained with later-generation lithotripters. The shock-wave source was placed in the same water compartment as the patient and there were accordingly minimal energy losses during shock-wave transmission. The shock-wave focus, although with a much lower energy density than in most modern lithotripters, had a very large volume (20 × 90 mm) and the diameter of the shock-wave reflector was accordingly relatively short (15 cm). This means that when the shock wave entered the body it passed through a much smaller tissue volume than in the majority of later-generation lithotripters. The shock waves, moreover, were electrocardiogram (ECG)-triggered and thus were delivered at a frequency close to 1 Hz.

The disintegration of renal stones is successful if fragments are formed that easily can be eliminated through the ureter. Early on it was established that a satisfactory disintegration should result in fragments or gravel of which no single component has a diameter exceeding 4 mm [11]. When remaining fragments have a diameter of 5 mm or more, an optimal disintegration has not been obtained. These definitions have been adhered to in most literature reports and most of the measurements have been made on plain films of kidney, ureter, and bladder (KUB). It needs to be added that more fragments can be identified with CT imaging than on KUB images [13], but for follow-up after ESWL it is much easier to judge stone disintegration with KUB than with CT images [14, 15].

Shock-wave transmission

A fundamental factor in the success of ESWL is uncompromised passage of the shock wave from its source (reflector, therapy head) to the focal point in the patient's body. When it was the practice to immerse the patient in the same water as the shock-wave source, as was the case with the Dornier HM3 device, this was not a potential problem. However, in most modern lithotripters, transmission of the shock wave into the patient's body is accomplished by application of a coupling medium, such as ultrasound jelly or silicon oil. In some lithotripters, the shock wave also has to cross the gap between the therapy head and a plastic foil, before entering the body; silicon oil is used at the first interface and, preferably, degasified water at the second. With all lithotripters, extreme care has to be taken to avoid loss of power during transmission.

Whatever the transmission medium used, it is crucial that a sufficient amount is applied so that the whole shock-wave cone enters the body. Moreover, this medium should be without air bubbles. Air bubbles can adhere to body hairs and for patients with a rich growth of hair, shaving at the point of assumed shock-wave entry should be undertaken to eliminate this cause of shock-wave attenuation.

Depending on the type of lithotripter that is used and whether the patient is treated with the shock wave coming from the back or from the abdominal side, various anatomic structures may interfere with the shock-wave path. If such obstacles are not considered by the operator, they can cause a considerable reduction in or even extinguish the disintegrating power. An imaging system that is in line with the shock-wave path facilitates their identification.

The effect of such interfering structures depends on where the stones and the kidneys are located and of course the direction in which the shock wave is traveling. The shading effect with attenuation of shock-wave energy is greater when the interference caused by an obstructing structure occurs close to the focus than if it occurs at a greater distance from the stone. Figure 51.3 shows a schematic example of how a skeletal structure such as a rib can interfere with the shock wave and

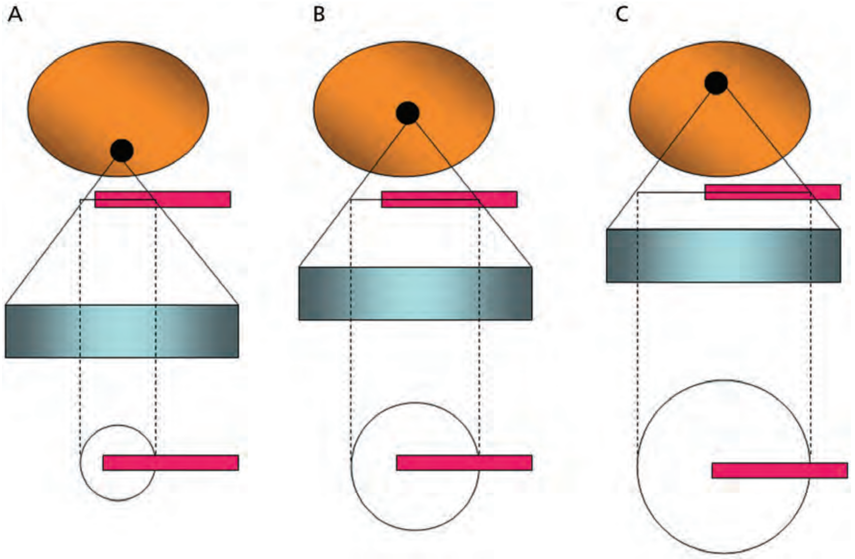

Figure 51.3 Relative interference of a skeletal structure (for instance a rib, indicated by the red rectangle) with the shock wave focused on a stone at various levels in the kidney. (A) Short distance between the stone and the rib and a long distance between the shock-wave source and the rib. The attenuation of the total shock wave energy in that situation is much more pronounced than when relatively smaller parts of the shock wave area are affected (B and C).

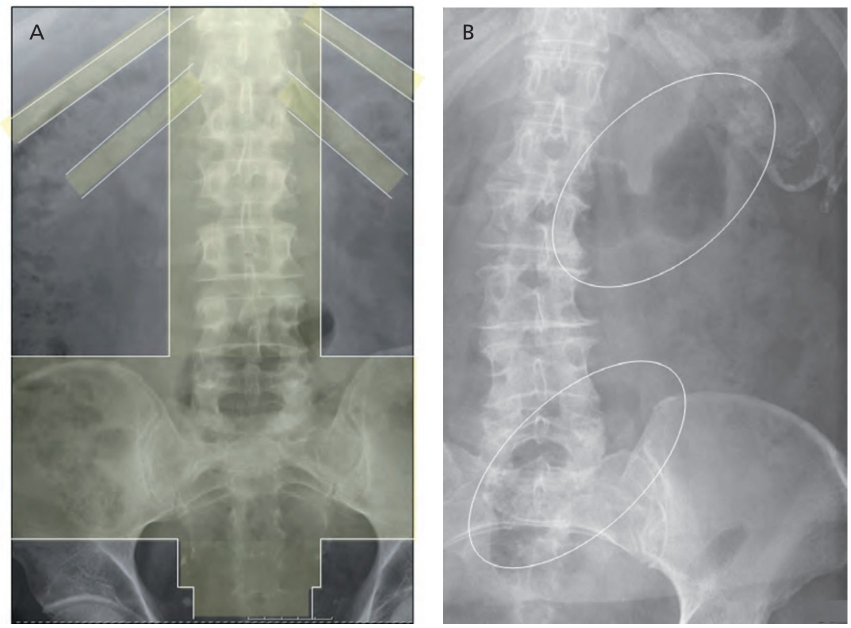

Figure 51.4 (A) Skeletal structures (ribs, spine, pelvic skeleton, and sacrum; highlighted) may attenuate the shock waves when these are directed from the back of the body. The sacrum and lower pelvis are of importance when treating stones in abnormally located kidneys (pelvic and transplanted kidneys). (B) Intestinal gas (ringed) needs attention in patients treated with shock wave directed through the abdominal cavity.

Figure 51.4A shows the important skeletal structures that can interfere with shock-wave propagation. The core of the spine itself or the transverse processes may reduce the transverse area of the shock-wave cone. A similar effect is exerted by the pelvic skeleton in case of kidneys with a low retroperitoneal position or by the ribs for stones located in the kidney. To manage such problems, the patient or the therapy head can be tilted or the shock waves can be administered from the abdominal side.

When the shock wave enters the body through the abdominal cavity, intestinal gas can constitute a barrier to transmission, making shock-wave treatment from that direction impossible or very inefficient (Figure

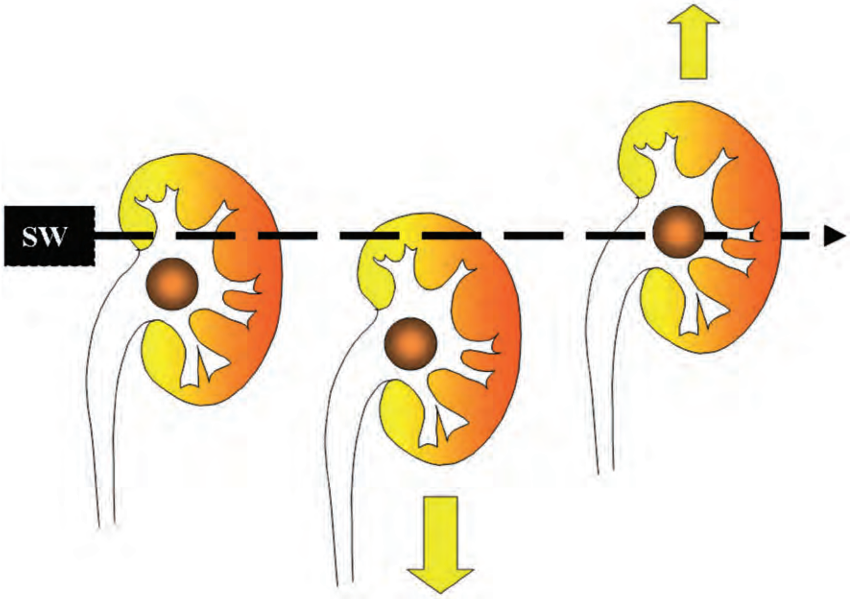

Figure 51.5 Positioning of stone(s) that move with respiration. SW, shock wave.

51.4B). Bowel preparation with dimeticon, enema, or occasionally macrogol (Laxabon) may be helpful, but in some situations it is necessary to postpone the ESWL until there is a more favorable intestinal gas distribution. Although gas can form or redistribute during an ESWL session due to the shock-wave effect on the intestine, a prediction usually can be made from a KUB before the treatment. In cases where it is likely or possible that the shock waves will need to be delivered through the abdominal cavity, we routinely give 300 mg of dimeticon three times daily for 5 days preceding the planned ESWL.

Another obstacle to the shock wave is a thick layer of subcutaneous fat, which has a different acoustic impedance. Moreover, in obese patients there is a longer distance from the skin level to the stone, and this distance has been suggested to be an important predictor for ESWL success [16]. Although the shock-wave attenuation caused by subcutaneous fat and other tissues in most thin and normal-weight patients can be ignored, the much larger tissue volume through which the shock wave has to pass in obese patients may have a significant influence on ESWL efficacy. In obese patients it may be necessary to increase the shock-wave power in order to achieve a satisfactory disintegration of stones [17] and to utilize the blast path technique in order to compensate for an insufficient penetration depth [17, 18].

With a small focal volume and the normal respiratory movement of the kidney, the hit rate of the shock wave can vary considerably. Several methods have been suggested to compensate for that problem. It is important always to place the stone in focus during the expiratory phase, because that is the period during which the kidney and stone remain in the same position for the longest period of time (Figure 51.5). Another trick that can easily be used is to apply a belt across the patient's upper abdomen or lower thoracic cavity in order to reduce the amplitude of the respiratory movements [19], ensuring of course that this does not negatively affect the patient's oxygenation. General anesthesia has been suggested to allow more controlled kidney movement [20, 21] and high-frequency jet ventilation [22], but the need for anesthesia reduces the versatility of ESWL. Another method is respiratory gated shock-wave generation, but that approach has not been particularly successful [23] and is not commonly used.

Experimental studies on the physics of electrohydraulic shock waves in terms of energy density (μJ/mm^2) indicated that better disintegration was obtained when the stone was placed below (in front of) the focal center. Under experimental conditions with an electrohydraulic lithotripter, the maximum disintegration was seen at a distance of 1–2 cm from the expected peak power region [24]. Whether or not this property also is applicable for electromagnetic shock-wave generation is not known, but it may be worthwhile to keep this observation in mind for SWL-resistant renal stones.

Treatment strategy

Optimal disintegration of stones requires a treatment strategy based on an understanding of the physics of the shock waves [25]. In clinical practice, usually a standard schedule with recommendations to the operator on how the treatment should be carried out is followed. Advice is given on the selection of shock-wave generator voltage (kV, energy level), rate of shock-wave administration, and maximum number of shock waves that should be given. Many of these standardized recommendations are arbitrarily chosen and dependent on the lithotripter used. This static approach is likely to give suboptimal results; moreover, it will undoubtedly often lead to overtreatment both in terms of number of shock waves and energy levels, with associated negative effects on the renal tissue. Recent experimental as well as clinical observations have given a better basis for designing a treatment strategy that hopefully can optimize the outcome and make the treatment even safer.

Shock-wave energy levels

It has been shown that shock-wave energy and stone disintegration improve with increased generator voltage, but significantly so only to a certain level after which the relationship plateaus [24]. A high generator voltage also results in larger fragments than a lower voltage. This property was clearly illustrated by the low power piezoelectronic systems [26]. Thus shock-wave energy should only be increased to a level that results in a satisfactory disintegration. Further increments with the aim of achieving better disintegration or shorter duration of treatment may result in a less satisfactory outcome. On the other hand, it is necessary to use a sufficiently high energy to achieve stone disintegration and that energy is dependent on the chemical composition of the stone. In as much as knowledge of the stone composition is the exception before the treatment, it is highly recommended to start the ESWL at a low energy level and to increase the power slowly until an energy level is reached at which disintegration occurs. Recent clinical observations have demonstrated benefits of increasing the shock-wave energy in a step-wise manner [27–29], but this effect has not been consistently reported [30]. Such a strategy is termed ramping and is commonly applied, at least in most centers that do not use general or regional anesthesia.

The bottom-line of these observations is that shock-wave energy levels should be as low as possible but sufficiently high to achieve stone disintegration. Such an approach also is of fundamental importance for avoiding injury to the renal tissue.

Number of shock waves

It stands to reason that the higher the number of shock waves the greater the risk of renal damage [31]. Certainly, a large number of high-power shock waves should be avoided. A relatively large number of shock waves is, however, necessary for stone disintegration at the energy levels that can be used clinically. Several factors determine the number that is needed, such as the stone volume [32], stone composition [33], size of the patient [16, 32], and the extent to which the shock waves hit the stone. Nevertheless, it can be assumed that many patients are probably over-treated in terms of shock wave number, with the intention to avoid repeat sessions. The problem is that when the surface of a stone disintegrates, fragments will reflect the incoming shock waves. Disintegration of the deeper parts of the stone therefore is difficult to achieve and our experience in such cases is that it is best to plan for a repeat session on another occasion when the small fragments have been eliminated. This is the reason why large renal stones generally require more treatment sessions than small stones. It is important to consider the repeat ESWL session(s) not as failure but as part of a careful and safe treatment strategy.

With a low-power setting it usually is possible to give more shock waves than with a high-power setting. Nevertheless, a maximum of around 2000–3000 shock waves during one treatment session has proven to be practical, possibly with the range of variation depending on the type of lithotripter and location of the stone.

Although these principles should be applied for all patients, it is particularly important to use them when treating children [31] and patients with certain risk factors [17]. General recommendations on energy levels and maximum number of shock waves cannot be given here; they need to be individually established for each lithotripter and each clinical stone situation.

Frequency of shock-wave administration

Today a majority of lithotripters has an electromagnetic shock-wave generator and with this ECG-triggered release of shock waves is unnecessary. Accordingly it is now possible and more common to use a wide range of frequencies for shock-wave administration. Frequencies between 0.5 and 4 Hz (i.e. 30–240/min) have been reported and one apparent advantage is that with a higher frequency the treatment sessions can be shortened.

Several experimental and clinical observations, however, have shown that a low shock-wave rate results in significantly better stone disintegration than a high frequency [27, 34–41]. Most studies have compared 1 Hz and 2 Hz, with best results observed in patients treated with 1 Hz [36–38, 40–42]. In patients given shock waves at 1.0, 1.5, and 2.0 Hz, the conclusion was that the overall outcome was best following treatment with 1.5 Hz [43]. Recent observations have indicated that an even lower frequency of 0.5 Hz may be superior to other frequencies [44, 45]. Such a low frequency setting is, however, not a common feature of most lithotripters today, and unless this approach significantly reduces the total number of shock waves needed, the prolonged duration of the treatment sessions perhaps makes it less attractive. It is important to note that the benefit of a low shock-wave frequency in terms of stone disintegration was most obvious for stones with a largest diameter exceeding 10 mm [39].

Whether or not a frequency of 1.0 Hz is better than 1.5 Hz is an unresolved issue, but it seems reasonable to avoid frequencies above 1.5 Hz and to reduce the frequency to 1.0 Hz when the expected disintegration is not obtained. In such situations it is reasonable to reduce the shock-wave frequency before further increasing the energy level. In addition to the benefits in terms of stone fragmentation, such a strategy also is recommended for reducing the negative effects of shock waves on the renal tissue [45, 46]. This matter is further discussed below.

The explanation that has been provided for the better disintegration with a lower shock-wave frequency is that cavitation bubbles that have not collapsed when the next shock wave hits, interact with and attenuate the incoming shock wave [47]. Also, cavitation bubbles remaining in the renal tissue are considered important for renal injuries.

Use of increased diuresis

With the intention of creating an expansion chamber around the stone [48] and possibly of moving fragments away from the stone surface, a forced diuresis has been our preference when treating kidney stones. Patients have been given a single 20 mg dose of furosemide together with a high pressure infusion of approximately 1000 mL of Ringer acetate solution during the treatment session. There are no randomized studies proving the efficacy of such a regimen, but experimental as well as clinical data have shown that fluid surrounding the stones may be associated with improved disintegration [48].

Interval between treatment sessions

One clinically highly important and common question concerns the frequency with which ESWL is carried out for kidney stones. Unfortunately this issue has not been fully elucidated. With the HM3 lithotripter, patients sometimes were given a second session after approximately 2 days. With the higher energy flux density of modern lithotripters, it seems wise to wait until the contusion or traumatic injuries to the renal tissue from a previous session have resolved. Kidney tissue damage caused by ischemic changes and reflected in coagulation and fibinolytic factors disappear after about 1 week [49]. Translation of these findings into clinical practice suggests an interval between ESWL sessions of at least 7 days, particularly if the same area of the renal parenchyma will be exposed to a new series of shock waves. In such cases we have routinely allowed 10–14 days between ESWL sessions.

Reduction of renal tissue damage and bleeding

Technical aspects

As mentioned above, a low rather than a high frequency of shock-wave administration, in addition to a better stone disintegration, is associated with less trauma to the kidney. Moreover, the risk of bleeding can be reduced by inducing a vasoconstriction by starting with a number of shock waves at a low power setting [50]. Based on animal experiments, it also has been suggested that the best vasoconstriction is obtained when a pause is introduced after a small initial number of low-power shock waves [27].

Attention to anticoagulation treatment

Although minor hematoma and contusions following ESWL of kidney stones are considered common [51], large and clinically more significant subcapsular bleedings fortunately are rare. When they occur they are, however, usually associated with severe pain, considerable blood loss, and variable effects on renal function. The development of a subcapsular or retroperitoneal hematoma is one of the most severe and feared complications of ESWL and precautions are necessary to counteract this risk. A definitive explanation for all renal hematomas cannot be provided, but certain obvious risk situations must be avoided.

It is essential to document any anticoagulation therapy that the patient is on. Pharmacologic agents containing salicylates should be stopped in due time before the treatment in order to re-establish a normal thrombocytic function. The recommendation is to stop such treatment 7–10 days before ESWL for kidney stones [11]. It needs to be emphasized that certain health and herb preparations contain substances that increase the risk of bleeding; a serious renal hematoma was described in a patient who had taken large amounts of garlic [52]. In all these patients it is good practice to measure the bleeding time and to postpone the treatment when this is prolonged.

Treatment with warfarin and other coumarol derivatives must also be stopped. In these cases it is sometimes necessary to discuss the medication with the patient's internist because problems may arise if it is interfered with. Replacement with small amounts of low molecular heparin (Fragmin) is necessary as long as the INR value is below the therapeutic range. The recommended daily dose of heparin is 2500–5000 U. Exceeding that dose may result in a significantly increased risk of bleeding during or after ESWL. The standard practice in our department is to give the last warfarin dose on the fourth day before the planned treatment, to refrain from warfarin administration during the following 3 days, and to administer low-molecular-weight heparin after the treatment on the day of ESWL. Treatment with a low dose of low-molecular-weight heparin subsequently should continue until a therapeutic INR level is achieved.

Appropriate medical steps need to be taken in all patients with other coagulation or bleeding disorders in order to avoid renal bleeding complications [17, 53].

Increased risk of renal hematoma in patients with hypertension

Numerous reports have shown that hypertension dramatically increases the risk of renal hematoma [17, 51]. ESWL must not be given to patients with hypertension and measurement of the blood pressure before ESWL for kidney stones is mandatory. As there is a relationship between stone formation and hypertension [54], it is not surprising that many patients who come to ESWL have a previously unrecognized hypertension. All these patients should be referred to an internist for adequate treatment before ESWL.

Other conditions associated with increased risk of bleeding

Whenever there is suspicion of calcified or brittle arteries in the kidney, great care should be taken with shock-wave delivery in terms of shock-wave number and power setting. Patients who should be considered at high risk are those aged over 65–70 years, or with diabetes mellitus or a history of hypertension, even when appropriately treated. Based on clinical experience but without specific literature support, it is our practice also to consider patients who have been on any kind of anticoagulation treatment to be at risk.

Management and prevention of complications

Hematoma

Fortunately renal hematoma are rarely encountered, with frequencies in the literature of around 0.5–4% [51, 55]. The diagnosis of a subcapsular or retroperioneal bleed is established with a CT examination. The hemoglobin value should be measured and blood given in accordance with the estimated blood loss. Conservative treatment is almost always the method of choice. Circulatory unstable patients may need intensive care and occasionally intervention or radiologic plugging, but our experience indicates this need is exceptional. Most patients recover well after a few days of bed rest. Renal function should be followed and the hematoma followed with regular CT images.

Infection

Another severe complication is urosepsis. Needless to say, in all patients with UTI or bacteriuria, pre-ESWL treatment with antibiotics according to the sensitivity pattern should be given. Because urinary tract stones frequently are associated with or occur together with asymptomatic bacteriuria, attention has to be paid to the potential risk of developing septicemia when the ESWL is carried out and bacteria are released.

Screening for bacteriuria with a dipstick test is recommended for all patients who come to ESWL. In case of a positive test, as well as in patients with a history of UTI or with a percutaneous nephrostomy catheter, an intravenous dose of antibiotics should be given approximately 1 h before the treatment. Sometimes a previous urine culture can be used to choose the most appropriate antibiotic regimen. In the absence of such information, a broad-spectrum antibiotic should be given intravenously. We have routinely used with great success aminoglycosides, such as gentamicin 120 mg or netilmicin 150 mg, but 1–2 g of ceftazidime or another cephalosporin may be a useful alternative. For a patient in whom the risk of infection is particularly pronounced and no percutaneous nephrostomy catheter is present, it is advisable to insert an internal stent before ESWL. Such a step aims to alleviate the risk of obstruction and stagnation of infected urine. For all patients with a positive bacteria test, a urine culture should be carried out and oral antibiotics continued for an appropriate period of time after the ESWL session.

Steinstrasse

It was an early observation that ESWL of large stones was associated with a risk of developing an obstructing accumulation of stone fragments in the ureter. The condition was called steinstrasse [11]. Only situations similar to that in shown in Figure 51.6 are of clinical relevance and need to be treated appropriately. It is, however, essential to prevent the formation of a steinstrasse. The rule that has been established is to insert a stent when the largest stone diameter exceeds 20 mm or when the stone surface area is greater than 200–300 mm^2 (as measured on a frontal view image) [11]. In some cases with smaller stones it also may be of value to counteract obstruction by stenting, particularly when a rapid passage of fragments can be anticipated and there is a risk of stagnation of infected urine.

Several methods have been suggested for dealing with a steinstrasse if it occurs. In the presence of

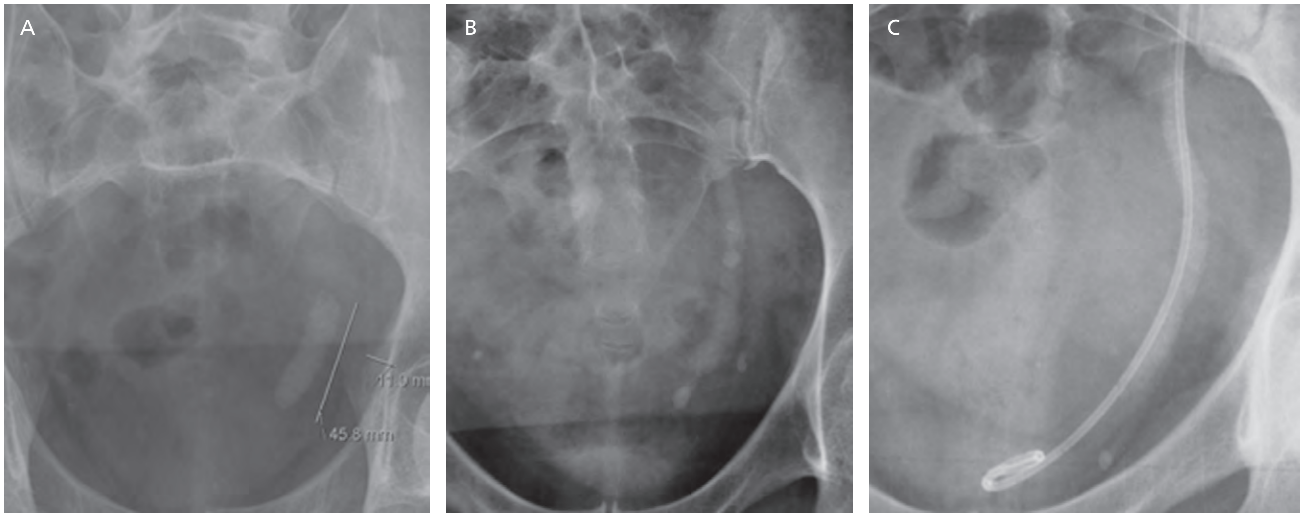

Figure 51.6 (A) Accumulation of well-disintegrated fragments obstructing the urine flow (steinstrasse) following shock-wave lithotripsy of a 30 × 30 mm stone in the renal pelvis. (B) A similar accumulation of fragments, but with larger stone residuals. (C) Accumulation of well-disintegrated fragments along an internal stent.

infection symptoms, the most appropriate step is to insert a percutaneous nephrostomy catheter after which well-disintegrated fragments usually pass. In the absence of infection, ESWL directed towards the steinstrasse may break up the fragment accumulation and disintegrate any leading or imbedded larger fragments (Figure 51.6B). Occasionally, it may be of value to loosen the impaction by instillation of a lubricant jelly through a ureteral catheter and to place a stent afterwards if the steinstrasse can be passed with a guidewire. With these steps almost all fragment accumulations can pass and it is our experience that a ureteroscopic approach is almost never necessary in these patients.

Pain

Episodes of renal colic are a reason for emergency visits or readmittance in the days immediately following ESWL. To counteract such problems, the routine administration of diclofenac twice daily for 5–7 days is recommended [56]. In addition, alpha-receptor antagonists or calcium channel blockers may be useful to facilitate fragment passage [3, 57].

Pharmacologic tissue protection

It has been shown that ESWL generates free radicals and that administration of antioxidants has a tissue protective effect. Treatment with allopuriol may counteract renal injuries [58, 59]. Tissue protection has also been observed with calcium antagonists [60]. Such treatment options should be considered in patients with reduced renal function and in those in whom repeated sessions can be foreseen.

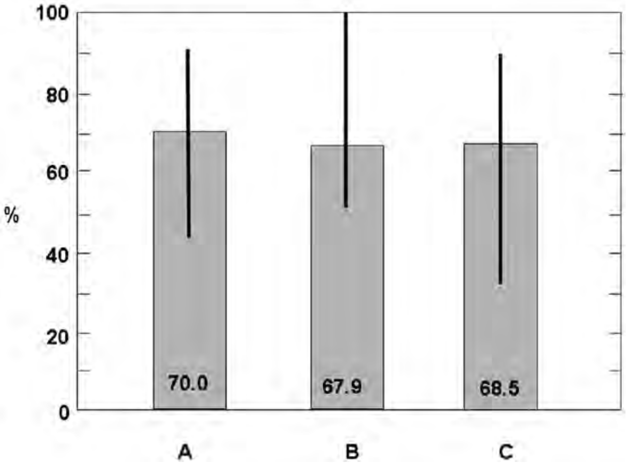

Figure 51.7 Mean and range stone-free rates in patients treated with electrohydraulic lithotripters up to 1989 [61] (A) with second- and third-generation lithotripters up to 1993 [61] (B), and from lithotripsy results reported between 2000 and 2009 [19, 20, 26, 30, 32, 62–69] (C).

Treatment outcome

Results of SWL for kidney stones are summarized in Figure 51.7. Data from the literature up to 1993 showed stone-free rates between 44% and 90% in 3231 patients treated with electrohydraulic lithotripters [61]. With electromagnetically generated shock waves in 16 307 patients, the stone-free rate ranged between 52% and 100%, with a mean stone-free rate of 67.9% [61]. With the piezoelectric technique applied in approximately 2000 patients, between 51% and 75% became stone free. For patients with renal stones treated with modern lithotripters between 2000 and 2009 [19, 20, 26, 30, 32, 62–69], the average stone-free rate was 68.5% (range 31–90%) (Figure 51.7), which is very similar to the rates seen with electromagnetic devices up to 1993. A correct interpretation of these results is, however, seriously hampered by the lack of information on patient selection and referral to ESWL, and the acceptance of repeated session. Nevertheless, the retreatment rate for the electrohydraulic systems varied between 6% and 46%, and for the electromagnetic systems between 7% and 32%. It is of note, and not surprising, that the retreatment rates were highest with the piezoelectric system, ranging between 14% and 51% and averaging 27%.

Of an unselected group of 420 patients with renal stones primarily treated in our department during 2008 with ESWL, excluding those with staghorn stones composed of cystine, calcium oxalate monohydrate, and brushite, 57% were completely stone free and 17% had minor isolated fragments measuring 1 mm or less. Thus, 74% could be regarded as essentially stone free. Another 20% had fragments of 4 mm or less and 4% larger fragments or stones. These results were obtained after 624 sessions, which gives an average of 1.49 sessions per patient. Auxiliary procedures were used in 22% of the patients. The stones had a mean (SD) surface area of 94 (172) mm^2.

Determinants of treatment outcome

Treatment results, need for retreatment and auxiliary procedures, as well as profile of complications are dependent on the type of lithotripter used, its physical properties and disintegration capacity. Moreover, the size and type of stone play a major role.

Stone burden

With a generous and unrestricted attitude to repeat ESWL, it can be stated that approximately 95% of stones can be satisfactorily disintegrated [2, 3]. Large stones, however, require more treatment sessions than small stones and the stone-free rate decreases with increasing stone size (Figure 51.8) [3, 32, 61, 63, 64, 70]. Why large stones, albeit satisfactorily disintegrated, are associated with significantly more residual fragments is less easy to understand. Such an outcome possibly can be explained by disturbed contraction forces of the calyceal system caused by large stones residing in the kidney for a long period of time [71].

In view of the greater need for retreatments and the poor fragment clearance following treatment of large stones, it has been recommended that stones above a certain size are better referred to other low-invasive treatment alternatives, such as PCNL or RIRS, particularly if located in the lower calyces [72]. There is, however, no consensus on the cut-off size. Some authors reserve ESWL for stones with a largest diameter not exceeding 20 mm [2, 19, 73, 74], whereas others set an upper limit of 15 mm [75, 76], 25 mm [77], 30 mm or more [68, 78, 79].

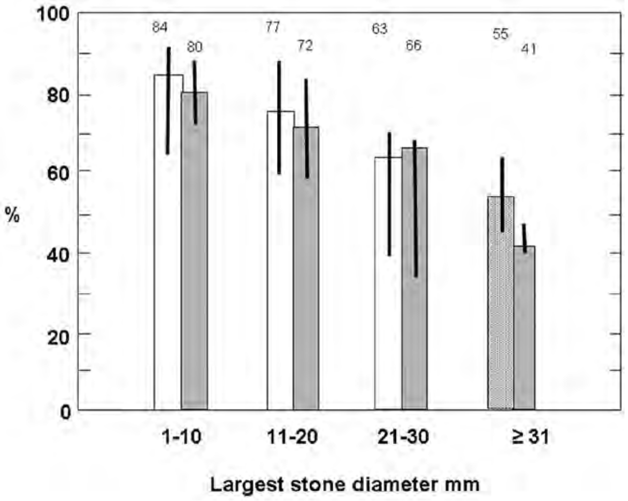

Figure 51.8 Mean and range stone-free rates recorded after shock-wave lithotripsy of stones in different size categories. The data were obtained from reports on treatment with the Dornier HM3 lithotripter (unshaded; the dotted column represents staghorn stones) [61] and with modern lithotripters between 2000 and 2009 (shaded) [3, 32, 63, 64, 70].

It is necessary also to consider the hardness (fragility) of the stone. Different stone constituents respond very differently to shock waves and clinical observations of their resistance to ESWL have allowed their hardness to be described in terms of their practical hardness factor (HF) [33]: cystine 2.4, brushite 2.2, calcium oxalate monohydrate 1.3, carbonate apatite 1.3, hydroxyapatite 1.1, magnesium ammonium phosphate 1.0, calcium oxalate dihydrate 1.0, and uric acid 1.0. Similar results have been reported by other authors [5, 17, 80, 81]. Knowledge of the stone composition allows a hardness index (HI) to be calculated from the HF [33]. A numerical estimate of the clinically relevant stone burden subsequently can be derived from the surface area and HI [82].

For determination of stone hardness in the absence of information on the chemical composition of the stone, CT examinations can be used as a guide and the stone density expressed in Hounsfield units (HU) [83–85]. There is, however, a considerable overlap between the HU values for different stone components. Recent advances in dual-source CT have proved to be a superior method for identifying various stone constituents, but this methodology is not yet commonly available [86, 87]. Therefore, in the majority of cases, the morphology and hardness of the stones has to be roughly estimated from their appearance on the KUB [14, 15].

Pareek *et al.* found that the best ESWL results were obtained when the stones had a density of less than 900 HU and when the skin–stone distance did not exceed 10 cm [16]. Similar results have subsequently been reported by others [5, 65, 88, 89].

Collecting system anatomy

Anatomic abnormalities may prevent fragment elimination from the kidney in different ways and the effect has to be judged in each individual case. Many of these patients may best be treated with alternative methods, as discussed elsewhere in this book.

Stones in the calyx diverticula are seen relatively often. Although the connection between such cavities and the other parts of the renal collecting system in most cases does not allow passage of fragments, a majority of these patients become asymptomatic after appropriate disintegration [90–92]. Therefore, primary ESWL rather than endoscopy may be a reasonable approach.

In medullary sponge kidneys (tubular ectasia), the stone burden is located inside the dilated collecting tubules and is inaccessible to ESWL. ESWL in those patients, however, may prolong symptom-free intervals by allowing elimination of stone material protruding into the calyces [93].

Stones in children

Several studies have clearly demonstrated that ESWL is an excellent procedure for active stone removal in children [77, 94, 95]. The principles are similar to those for adults with the exception that stents seldom are necessary even when large stones are treated [77]. It is particularly important to use low energy levels and a limited number of shock waves in children. Moreover, for most children it is necessary to use general anesthesia for an optimal treatment.

Stone location and fragment elimination

As illustrated in Figure 51.9, the location of the stone is a determinant of the treatment outcome. Stone-free rate is lowest for stones originally located in the lower calyx, but the differences in mean stone-free rates are relatively small. The lower calyx is the most common place for renal stones when first diagnosed with as many as 35% in that location (see Figure 51.1).

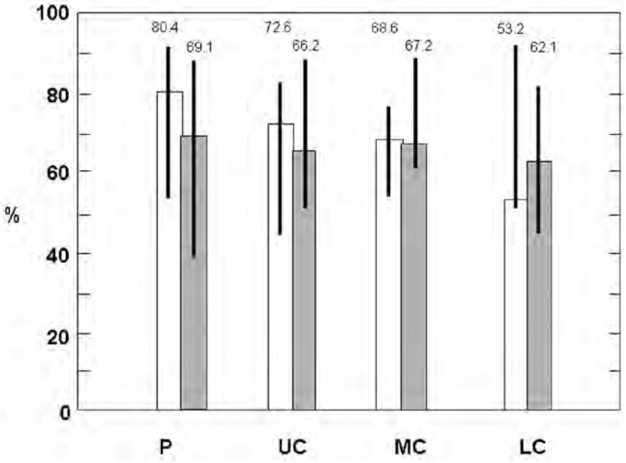

Figure 51.9 Mean and range stone-free rates reported for renal stones located in the renal pelvis (P), upper calyx (UC), middle calyx (MC), and lower calyx (LC) after treatment with the Dornier HM3 lithotripter up to 1993 (unshaded) [61] and with modern lithotripters 2000–2009 (shaded) [3, 32, 62–67, 70, 89]

The occurrence of residual fragments at follow-up is one of the major concerns after ESWL for renal stones. It is well recognized that the majority of residual fragments are found in the lower calyceal system (Figure 51.10A). This is thought to be an effect of gravity, because even for stones initially located and treated in other parts of the kidney, the lower calyces are the most common place for residual fragments. This is shown by the findings in more than 335 patients with residual fragments recorded after ESWL (Figure 51.10B). Although as many as 79% of the residuals were found in the lower calyces, in 34% of the patients the treated stone had not been located in the lower calyx.

Whereas some authors have suggested that stones in the lower calyx, particularly if larger than 10 mm in diameter, should be referred for alternative stone removal methods [96], others have shown that acceptable results can be obtained with ESWL for stones with a largest diameter of up to 20 mm [74].

A large number of reports have dealt with the geometric features of the lower calyceal system and several determinants have been suggested to predict stone clearance [97–102]. Although contradictory results have been reported, outcome of ESWL has been attributed to the calyx length, calyx width, angles of the outflow direction, infundibulum height, as well as the volume of the collecting system [79]. It has thus been suggested that a geometric analysis should be undertaken before deciding on the most appropriate form of treatment [100]. Although these different measurements can be used as a guide to future clearance problems, they usually cannot reliably predict the passage of fragments [103]. Statistical differences in stone-free rates related to anatomic findings are usually small. Most of these geometric analyses have been carried out on urographic images. On standard noncontrast CT examinations without three-dimensional image reconstruction, the corresponding measurements are not easily obtained. It is our opinion that information on the lower calyx anatomy today mainly is of theoreti-

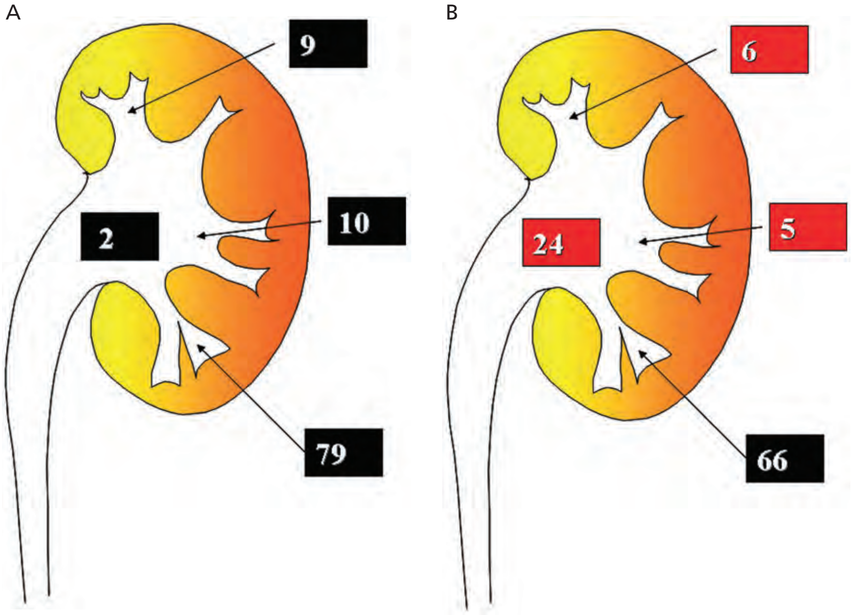

Figure 51.10 (A) Distribution of fragments in 335 patients with residuals after shock-wave lithotripsy and (B) the original location of the treated stones.

cal interest in a close follow-up analysis, and we do not look at the lower calyx anatomy before proceeding to ESWL.

There may, however, be a place for the analysis of lower calyx anatomy with the purpose of selecting those patients who may benefit from procedures aimed at facilitation of fragment elimination [62, 102]. In this regard, some authors have successfully used inversion therapy to improve stone clearance, in combination with vibration or percussion [104, 105]. Even when such an approach cannot be provided, instructing selected patients in various inversion movements may be rewarding.

Pharmacologic treatment aiming at improving stone clearance comprises alpha-adrenergic receptor antagonists, alkaline citrate, and diuretics. In a recent meta-analysis of 29 reports, it was suggested that patients treated for kidney stones should be offered supportive treatment with alpha-receptor blocking agents [57, 106, 107]. Several reports also have shown that treatment with alkaline citrate resulted in a significantly higher stone-free rate than when no such treatment was given [10, 108, 109].

Whether high diuresis after ESWL is of value for faster fragment elimination has not been unequivocally shown, but it is likely that such a regimen may be helpful, at least during the first days following a successful stone disintegration [63].

A major issue of concern is what should be done with those patients in whom residual fragments persist. There is a consensus that those who have *symptomatic* residuals should be offered active stone clearance [11, 53]. ESWL is one option, but alternative methods such as PCNL, RIRS, or chemolysis (when appropriate) should be considered. Similarly, additional treatment should be considered for *asymptomatic* patients with residuals that are unlikely to pass spontaneously through the ureter [11].

For *asymptomatic* smaller residual fragments, in the literature termed clinically insignificant residual fragments (CIRF), there is a lack of consensus on how to proceed, because it is generally assumed that residual fragments constitute a potential risk for new stone formation. Although that is an indisputable argument, far from all fragments will result in the formation of new symptomatic stones. For infection stone residuals, as well as for patients with cystine, uric acid, or brushite residuals, there is a pronounced risk of new stone formation (see below), but for most calcium stone residuals the further course of the disease cannot be predicted and there is no consensus on how to deal with such residuals [110–113]. In a 4-year follow-up of patients with calcium stone residuals (≤4 mm) in our department, 52% had unchanged or insignificantly increased stone volumes. New stone formation unrelated to the residual fragments was seen in 12% and obvious growth or consolidation without any symptoms in 14%, but progress to a symptomatic stone situation requiring repeated stone treatment was seen in only 12% [110]. In other reports the course of residual calcium stone fragments and the need for repeated treatment were at a similar level [110, 113, 114].

It stands to reason that the recurrence rate is higher in kidneys with residual fragments than in those without, but even stone-free patients have been reported to have a higher than expected recurrence rate following SWL (a 5-year risk of approximately 50%) [115]. A definitive explanation for this has not been provided, but it can be assumed that microscopic residual fragments serve as nuclei for new stone formation [116]. It would seem desirable, at least in our opinion, not to aggressively over treat the asymptomatic patients with the aim of making them absolutely free from stone fragments. For patients with residual renal fragments or stones it is, however, essential that a regular follow-up system is part of the long-term management [110, 114]. Moreover, it is recommended that these patients are offered recurrence prevention according to a biochemical risk analysis [10, 67, 110]. It is worthwhile noting that patients with residuals receiving medical treatment after PCNL had a significantly lower risk of developing stone recurrences [117, 118]. How the metabolic evaluation should be carried out is beyond the scope of this chapter [11].

Methods to describe treatment results

A stone-free status is the definite goal of each ESWL, but to achieve this may require several treatment sessions as well as auxiliary procedures. Therefore, ESWL results are often expressed as an efficiency quotient (EQ) according to the following formula:

$$EQ = \frac{100 \cdot SF\%}{100 + repeated\% + auxillary\%}$$

where SF% is the percentage of stone-free patients, and repeated% and auxillary% are the percentage of repeated SWL and auxiliary procedures [119]:

As the result is highly dependent on the stone burden, a stone treatment index (STI) was derived based on the number of stone-free patients (N_{SF}), ESWL sessions ($N_{SESSION}$), auxiliary procedures (N_{AUX}), and complications (N_{COMP}), as well as number of patients treated with regional or general anesthesia (N_{ANE}) [82]. Moreover, the stone burden was expressed as $\text{mean}\left(\sqrt{SA} \cdot HI\right)$, in which SA is the stone surface area and HI an expression of the stone hardness derived from the hardness factors, HF (see above) and the stone composition. To that were added factors for the patients age divided by 50 (Age_R), body mass index (BMI) divided by 25 (BMI_R), and the mean number of anatomic abnormalities (N_{ANA}):

$$STI = \frac{N_{SF} \cdot \left(\sqrt{SA} \cdot HI \cdot BMI_R \cdot Age_R \cdot [1 + N_{ANA}]\right)}{(N_{SESSIONS} + N_{AUX} + N_{ANE} + N_{COMP})}$$

The STI is useful not only for ESWL -treated patients but also for comparison of different stone-removal procedures in both patient groups and individual patients. It should be noted that a high STI is better than a low one. This index can be derived for both stone-free kidneys (STI_{SF}) and for those with a satisfactory disintegration (STI_{FR}). As an example, a 40-year-old patient with a BMI of 30, SA of 100 mm^2 and HI of 1.20, without anatomic abnormalities and who is stone-free after two ESWL sessions without anesthesia, auxiliary procedures, and complications, has an individual STI of 5.76. This can be compared with a similar outcome following URS with one session, one removal of a stent and general anesthesia, which gives an STI of 3.84. Renal stones may require significantly different treatment efforts, as shown in the three examples of ESWL for renal stones in Figures 51.11–51.13. Individual STI values were calculated for each of the four kidneys. For the right kidney with residual fragment in Figure 51.13, the STI reflects the efforts necessary to achieve satisfactory disintegration.

Chemolytic considerations

Whereas calcium stone residual fragments or stones, with the exception of brushite, have a variable course and in many cases appear to remain surprisingly stable, this is not true for infection, cystine, and uric acid stones. These latter stone fragments, as well as brushite residuals, almost always give rise to new stones [110, 114, 120]. In those patients a much more extensive clearance of fragments is necessary and chemolysis is a very useful tool for this.

The primary procedure for removal of partial or complete staghorn infection, cystine, uric acid, and brushite stones is PCNL or occasionally RIRS, but even with these invasive procedures residual stones and fragments will be encountered [117, 121]. A combined so-called "sandwich" approach is often used in such cases [122]. This means that following the primary percutaneous approach, remaining stones are disintegrated with ESWL and in case of persisting residuals a second PCNL or RIRS procedure is used to finally clear the collecting system. When a percutaneous nephrostomy catheter is already in place chemolytic options are available for stones containing magnesium ammonium phosphate, carbonate apatite, brushite, uric acid, and cystine, but not for calcium oxalate stones or stones with a significant fraction of calcium oxalate [123–125]

Hemiacidrin (Renacidin®) [124, 125] or Suby's solution [123] are excellent alternatives for dissolution of infection stone and brushite stone fragments, and are also useful for other calcium phosphate salts. For uric acid stone residuals, alkaline solutions of 0.3 mol/L or 0.6 mol/L THAM (trihydroxy-methyl-amino-methane) can very rapidly clear the system [11, 113]. We routinely use oral chemolysis with alkaline agents in case of uric

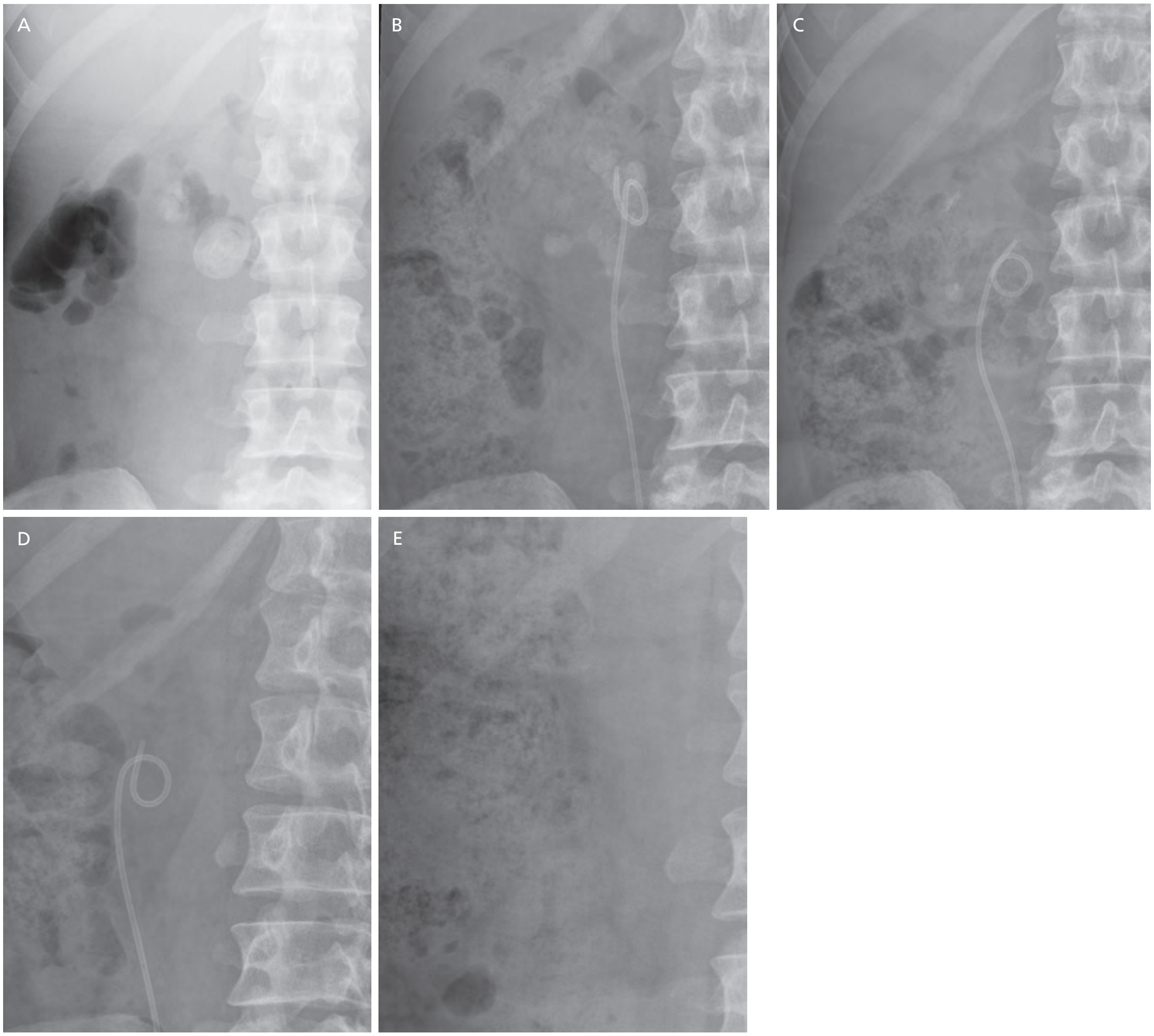

Figure 51.11 A 688 mm^2 stone in the right kidney of a 40-year-old woman. The stone situation before treatment (A) comprised three stones with diameters 30 × 24, 11 × 7, and 10 × 8 mm. The kidney became stone-free (E) after three shock-wave lithotripsy sessions with a total of 8450 shock waves (B–D). Treatment was carried out with an internal stent and the STI_{SF} was 4.8.

acid residuals of limited size. The combined use of THAM solutions and acetylcysteine can advantageously be used for elimination of cystine fragments [126, 127]. Chemolytic irrigation may be of value also in those cases where the collecting system is regarded as sufficiently cleared of microscopic residuals.

When chemolytic treatment is carried out it is essential to avoid high pressure infusion. Therefore *two* nephrostomy catheters should be in inserted: one for inflow and one for outflow. Although methods have been designed for pressure measurements, this is usually not a necessary device and we have not used this method in several hundreds of chemolytic treatments. A broad-spectrum antibiotic should be given parenterally before starting chemolysis in order to avoid infection. An internal stent is recommended to maintain a urine flow to the bladder and to avoid stone passage down the ureter.

For patients with soluble staghorn stones who are either medically unfit for general or regional anesthesia or who have other factors excluding percutaneous surgery, a combined approach with repeated ESWL sessions and percutaneous chemolysis can be used (Figure 51.14) [128]. This method has been successful in a number of patients with infection, brushite, uric acid, and cystine stones. The ESWL is used to increase the stone surface area to be exposed to the chemolytic solutions. Although this method is time consuming, it nevertheless provides a treatment alternative for many

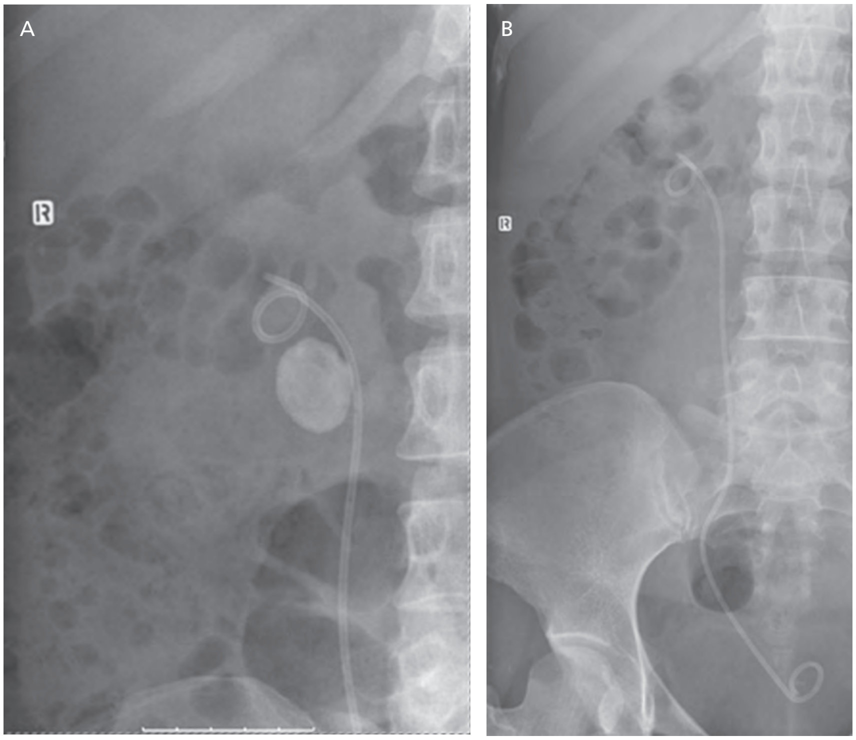

Figure 51.12 (A) Patient with a stone of surface area 358 mm^2 (24 × 19 mm). (B) The stone was sufficiently disintegrated with one shock-wave lithotripsy session (3200 shock waves) and the kidney became stone free. STI$_{SF}$ was 6.4.

patients when other methods are impossible or less desirable.

Chemolytic solutions for different stone components are summarized in Table 51.2.

Recommendations and contraindications

Whether SWL is an appropriate treatment method for a defined stone problem is dictated by several factors. To give strict recommendations is not possible because the attitudes of the patient as well as of the treating urologist, together with both medical and economic issues, play a role. One fundamental prerequisite is that there is an outflow from the kidney that will permit fragments to pass.

The question of which patients should be referred to ESWL can be addressed by first identifying those patients in whom ESWL is not an indication. Pregnancy is an absolute contraindication to ESWL [17]. Similarly, uncorrected bleeding disorders, ongoing medication with anticoagulation agents, as well as untreated hypertension exclude patients from ESWL. It is considered contraindicated to give shock waves to patients with aortic or renal artery aneurysms, at least for stones that are located close to such pathologic structures [73]. This is probably a wise recommendation, but ESWL in patients with aortic aneurysms is not an absolute contraindication [129].

For patients with complete or partial staghorn stones, ESWL is not the first choice. Although large infection stones can be appropriately eliminated by a combined approach with ESWL and chemolysis (see above), ESWL monotherapy is discouraged. Stones of other chemical composition should be removed by PCNL, particularly when composed of cystine, calcium oxalate monohydrate, or brushite.

The upper size limit for a stone that should be treated with ESWL has been a matter of debate. Most authors agree that ESWL is the primary method for stones with a diameter up to 20 mm [113], but others have treated larger stones. There is, however, a need to consider that treating larger stones will require several treatment sessions as well as stenting, but that is a choice that the patient often makes given the noninvasive or at least minimally invasive character of ESWL.

Specific factors that should be taken into account are the stone composition and location. Large brushite, calcium oxalate monohydrate, and cystine stones are usually more effectively eliminated percutaneously. This may also be the case for large stones in the lower calyx, as discussed above.

Recommendations for successful ESWL for renal stones are listed in Table 51.3 and suggestions for post-ESWL treatment to avoid pain and improve fragment elimination in Table 51.4.

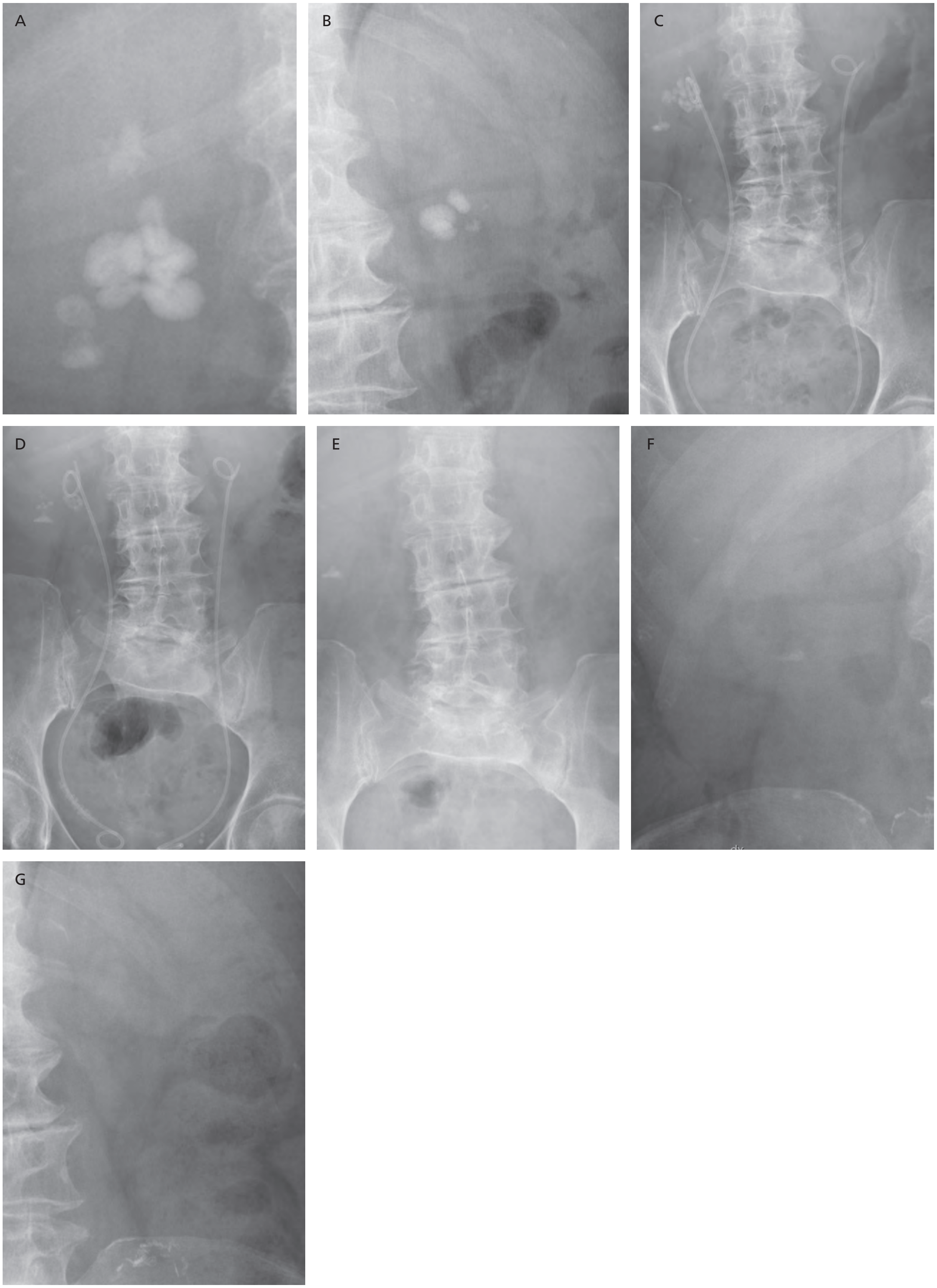

Figure 51.13 Bilateral stones in a 75-year-old woman of surface areas (A) 637 mm^2 and (B) 196 mm^2. There were three shock-wave lithotripsy sessions for the right-sided stone (7300 shock waves) and one for the stone on the left side (700 shock waves). Whereas the left kidney became stone free (C, D), the right kidney had a collection of asymptomatic fragments at follow-up (E–G). Stents were used bilaterally to allow for safe treatment of the two kidneys at short intervals. STI_{SF} for the left stone was 8.7. The corresponding STI_{FR} for the right stone (*disintegrated* stone) was 7.8 (although expressed in terms of stone-free kidney, the right STI is of course 0).

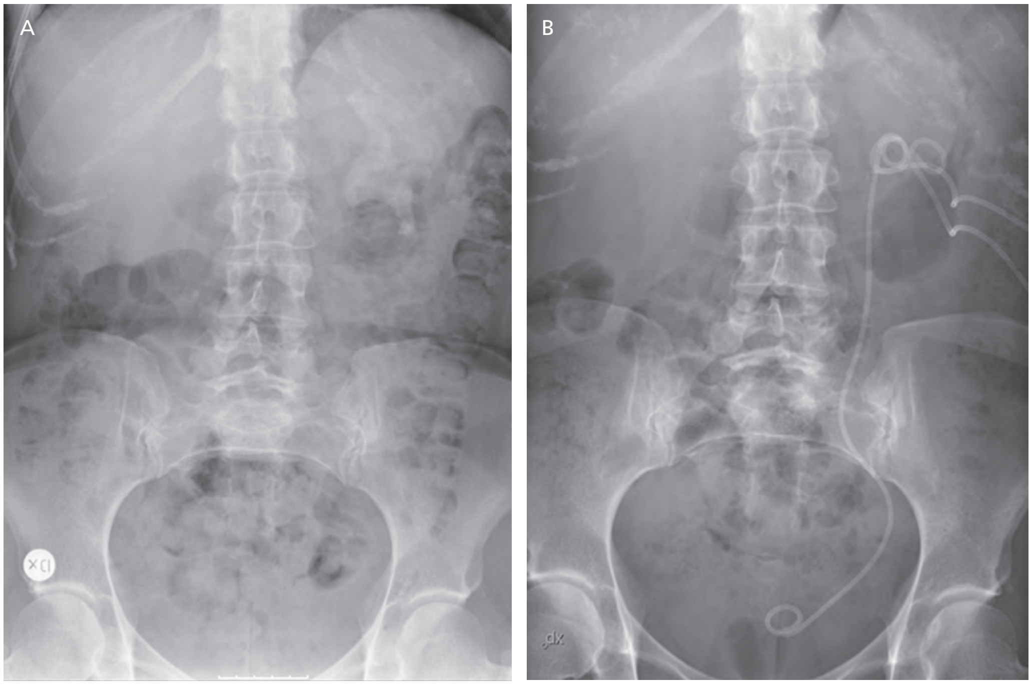

Figure 51.14 (A, B) A complete infection staghorn stone with a surface area of 1770 mm^2 successfully treated with a combination of shock-wave lithotripsy (SWL) and chemolysis. Treatment was completed in 10 days with three SWL sessions (5100 shock waves) and 15 000 mL of hemiacidrin. The short interval between the repeat sessions was possible because different parts of the kidney were treated on each occasion.

Table 51.2 Which chemolytic agent should be chosen?

Stone constituent	Chemolytic agent
Magnesium ammonium phosphate (struvite)	Hemiacidrin (Renacidin) 10% (or 5%) *or* Suby’s solution G
Carbonate apatite	Hemiacidrin (Renacidin) 10% (or 5%) *or* Suby’s solution G
Brushite (calcium hydrogen phosphate)	Hemiacidrin (Renacidin) 10% (or 5%) *or* Suby’s solution G
Hydroxyapatite	Hemiacidrin (Renacidin) 10% (or 5%) or Suby’s solution G
Octacalcium phosphate	Hemiacidrin (Renacidin) 10% (or 5%) *or* Suby’s solution G
Calcium oxalate	No chemolytic agent available
Uric acid*	THAM solution 0.6 or 0.3 mol/L
Ammonium urate	No chemolytic agent available
Xanthine	No chemolytic agent available
Cystine	THAM solution 0.6 or 0.3 mol/L in combination with acetylcysteine solution 2–5% (pH 8)
2,8-dihydroxyadeneine	No chemolytic agent available

*Also add oral chemolysis with alkali (sodium bicarbonate, potassium citrate, or sodium potassium citrate) and allopurinol to reduce high levels of P-urate and U-urate.

Table 51.3 Recommendations for successful shock-wave lithotripsy for renal stones.

Make sure that the coupling between the shock-wave source and the patient is optimal
Place the stone in focus during the expiratory phase
Reduce respiratory movement with a belt
Check the position of the stone frequently during treatment
Start the treatment at a low energy level
After a small series of shock waves, a pause of 2–3 min may be of value, particularly in patients with a high risk of bleeding complications
Never exceed a shock-wave frequency above 90 per minute or 1.5 Hz
Reduce the frequency to 60 per minute or 1.0 Hz if insufficient or absent disintegration
Do not exceed shock-wave energy above levels where an obvious disintegration occurs
Avoid unnecessary over-treatment
In case of “jumping stones,” reduce the shockwave energy
In patients for whom repeated sessions are expected, consider administration of renal tissue protective agents
For patients with a positive bacteriuria test, positive culture or a history of urinary tract infection, give an intravenous dose of a broad-spectrum antibiotic 1 h before the treatment
Never treat patients with uncorrected hypertension
Never treat patients with uncorrected coagulation disorders
Stop treatment with salicylates and warfarin as detailed in the text
Give sufficient analgesics and sedatives to avoid patient movements and to allow an uncompromised choice of shock-wave energy
Make sure that the shock-wave path is free
A forced diuresis during the treatment may be beneficial
Allow 10–14 days to elapse between repeated treatment sessions
If no disintegration can be observed, search for possible obstacles
If extraventricular beats occur, consider use of ECG-triggered shock waves. In bradycardia, give atropine
Administer oxygen during the treatment and measure oxygen saturation continuously

Table 51.4 Suggestions for post-shock-wave lithotripsy treatment to avoid pain and improve fragment elimination.

Give 50 mg diclofenac suppositories twice daily for 5–7 days
For appropriate patients, give an alpha-receptor blocker for 10–30 days
A treatment course of a diuretic may be useful, and potassium citrate may compensate for potassium losses
For appropriate patients, give instructions for inversion treatment

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CHAPTER 52

Shock-Wave Lithotripsy of Ureteral Calculi

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Introduction

The last decade has seen the mainstream use of flexible and small-caliber ureteroscopy (URS) combined with laser techniques for stone fragmentation, in addition to traditional pneumatic devices. In spite of this progression towards improved efficacy and availability of URS for treatment of ureteric calculi, extracorporeal shock-wave lithotripsy (ESWL) remains a valid first-line treatment for ureteric stone disease due to its noninvasive nature, safety, and ease of treatment.

Shock-wave lithotripsy principles

Evolution of technology and physics

The ability of lithotripters to fragment stones relies on laws of acoustic physics, namely the production of a wave of energy consisting of a sharp peak in positive pressure followed by a trailing negative wave. All lithotripsy machines require a method of stone localization, an energy source to generate a shock wave, a device to focus the shock wave on an intended target, and a coupling mechanism to transfer the shock wave to the body [1–3]. The three main types of shock-wave generation available for use are electrohydraulic, piezoelectric, and electromagnetic [4].

Ultrasound and fluoroscopy remain the standard for ureteral stone localization prior to ESWL, and combined systems allow some compensation for the potential limitations of each modality. Ultrasound is useful for localization and realtime monitoring of stone manipulation for renal calculi and radiolucent stones, but is inferior to fluoroscopy for ureteral stone localization due to a lack of a clear acoustic interface. The presence of a hydronephrotic ureter will assist localization of ureteral stones to be treated by ESWL. Distal to areas of ureteric dilation, the use of ultrasound as a localization technique for ESWL is limited. Conversely, fluoroscopy requires additional operating room space and stone radio-opacity, and carries inherent risks of ionizing radiation. Radiolucent ureteral stones can be located with fluoroscopy using contrast, which can be instilled in an intravenous, retrograde or antegrade fashion [5]. Modular designs of current modern lithotripters allow use of fluoroscopy without the unit being attached to the machine, thus minimizing space requirements and allowing portability [6].

Mechanisms of stone fragmentation

Continued research in the last decade has improved our understanding of the mechanism of stone destruction, as well as concomitant tissue injury in ESWL. Urinary calculi are vulnerable to shock waves due to the imperfections in their structure, resulting from heterogenous crystallization of minerals and organic matrix. The mechanisms for stone fragmentation are a combination of compressive fracture, spallation, and cavitation [4].

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Compressive fracture

As the shock wave is propelled through tissue and to the stone, tensile cracking results due to forces imparting stress on stone imperfections and defects. Eisenmenger used *in vitro* studies of stone fragmentation to propose a circumferential "squeezing" effect of shock waves on urinary stones, based on the premise that shock waves travel faster in stone than water [7]. Provided that the focal point of the shock waves generated is larger than the stone, this should result in perpendicular and parallel cracks.

Spallation

This process involves the reflection and inversion of part of the shock wave back on to the stone as the shock wave leaves the posterior surface of the stone. This is due to the change in impedance at the stone–fluid interface, and if the reflected negative pressure exceeds the tensile strength of the stone, comminution of the stone will occur at sites of weakness.

Cavitation

This process involves the formation and collapse of bubbles as sound waves propagate through a fluid medium. As the generated shock wave travels through the body, the negative pressure wave creates bubbles at the stone–fluid interface, which increase in size as pressure falls. As the pressure increases with the positive component of the wave, these bubbles collapse violently and the resultant energy release contributes significantly to stone fragmentation [8–11].

Dynamic fatigue

During the course of ESWL treatment, the stone is subjected to multiple forces, leading to cracks and changes to its surface. The accumulation of damage leads to "dynamic fatigue," and ultimately, fragmentation of the stone [12].

Mechanisms of tissue injury

Although clinical experience with ESWL has demonstrated its safety, undesired tissue injury remains a concern, and studies in the last decade have shed significant light on the mechanisms of ESWL-induced tissue injury. In a review of current literature, Weizer *et al*. categorized these mechanisms: cavitation-induced renal injury, renal vasoconstriction and ESWL-induced renal injury, and free radical-induced renal injury [4].

As mentioned above, cavitation bubbles contribute significantly to stone fragmentation. However, tissue injury resulting from their formation in microvasculature and renal tissues is an unwanted effect of ESWL [13, 14]. Further studies are required to demonstrate if modifications to lithotripters to reduce parenchymal and intravascular cavitation can be performed without compromising stone destruction. These potential collateral tissue effects of cavitation are fortunately less critical in the management of ureteral as opposed to renal calculi (see Chapter 51), as surrounding tissue is less important to homeostatic function than renal parenchyma.

Factors influencing extracorporeal shock-wave lithotripsy in the management of ureteral calculi

Stone factors

Stone location

Proximal ureteric calculi

Calculi located in the proximal ureter are generally easily treated with ESWL (Figure 52.1). Some studies have shown earlier clearance of such stones using URS techniques as compared to ESWL, with the latter potentially requiring multiple attempts before radiologic evidence of stone clearance. This may mean a longer symptomatic period, as well as further use of hospital resources to retreat these patients. A prospective trial performed by Karlsen *et al*. in 2007 demonstrated a 58% stone-free rate with ESWL for 5–10-mm proximal ureteric stones at 3 weeks, compared to 79% with URS, although the difference was not statistically significant [15]. However, at 3 months similar stone-free rates were seen (88% for ESWL and 89% for URS). In 2008, Ziaee *et al*. performed a prospective trial comparing ESWL to URS for 10–15-mm proximal ureteric stones and demonstrated overall stone-free rates at 3 months of 78.6% and 72.5%, respectively [16]. Both ESWL and URS are considered appropriate first-line choices for treatment of proximal ureteric stones with overall stone-free rates of 82% and 81%, respectively, as shown in a recent large meta-analysis [17].

Mid-ureteric calculi

Calculi located in the mid-ureter are generally more difficult to treat with ESWL. This can be attributable to the increased difficulty of stone localization and inefficiency of shock-wave transference to the stone. Treatment using a posteriorly-oriented therapy head is often improbable due to the attrition of wave energy on the bony pelvis, and as such ESWL may be best performed in the prone position. In a large series of 598 patients, Tiselius was able to demonstrate stone-free rates of 97.8% for mid-ureteric calculi with one or more sessions

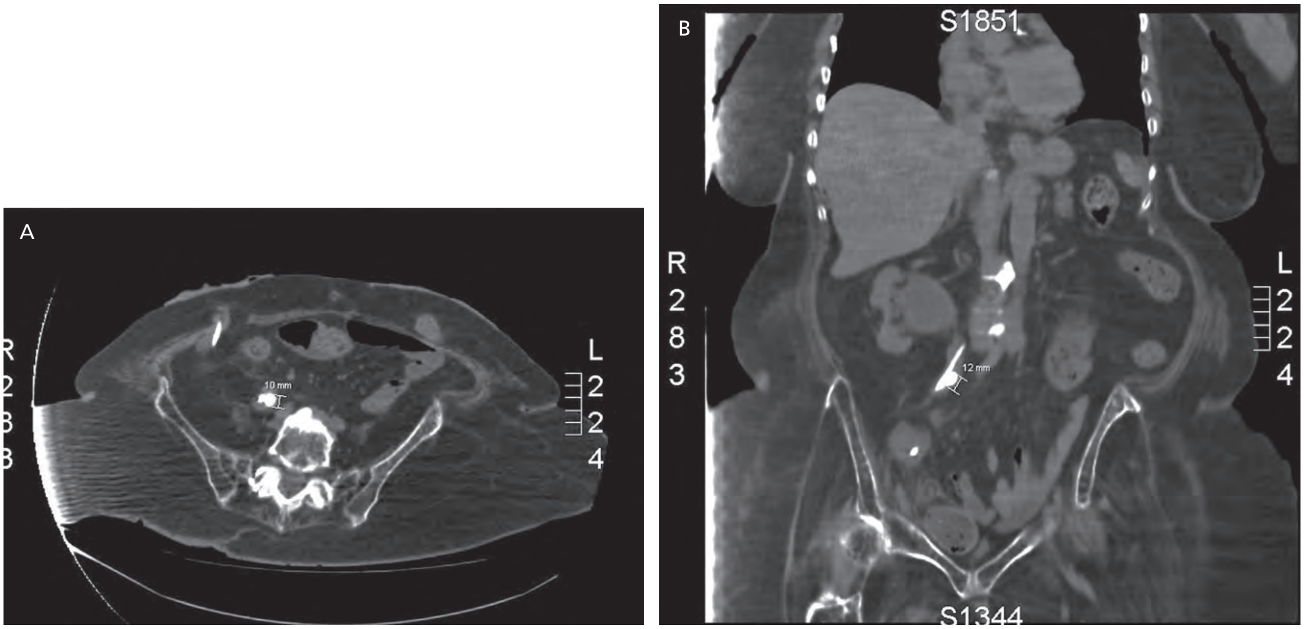

Figure 52.1 (A) Axial and (B) coronal CT images of a 72-year-old female with T5 paraplegia and ileal conduit and colostomy. Images demonstrate a 12-mm stone at the superior end of the right mid ureter adjacent to a ureteric stent.

of ESWL, but with a single treatment session being successful in 66.7%, compared to 73.1% and 83.2% in the proximal and distal ureter, respectively [18]. Stone-free rates for mid-ureteric stones by means of URS as a single procedure have been shown to be as high as 80–90% [19, 20]. For mid-ureteric calculi larger than 15 mm, stone clearance at 3 months was shown to be only 39.1% for ESWL, compared to 79.2% for URS [20].

Distal ureteric calculi

Stones located in the distal ureter are also amenable to treatment with SWL. The American Urological Association (AUA) Clinical Guideline Panel in both 1997 and 2007, the latter in conjunction with the European Association of Urology (EAU), performed a meta-analysis that demonstrated median stone-free rates of 86% and 74% for distal ureteric stones less and greater than 10 mm, respectively [17]. For URS, median stone-free rates of 97% and 93% were demonstrated for stones less and greater than 10 mm, respectively.

Stone size

Several studies have demonstrated that increasing stone size is associated with lower clearance rates with ESWL than for comparable smaller stones, necessitating retreatment with ESWL or secondary procedures [16, 21–23]. When comparing ESWL to URS for larger stones (>10 mm) in the proximal and distal ureter, stone-free rates are higher in the URS managed groups [17]. Stone-free rates for proximal ureteric calculi have been reported to fall from 80% to 44% for calculi larger than 10 mm [24].

However, with multiple ESWL sessions, some authors have shown overall stone-free rates for proximal and distal stones to reach 96.1% and 97.9%, respectively [18]. The AUA/EUA meta-analysis failed to show any statistically significant difference between ESWL and URS for successful treatment of ureteric stones of all sizes [17]. Other studies have shown ESWL to be inferior to URS for treatment of larger stones in the mid ureter, with multiple sessions often required, and thus most authors advocate URS as the treatment of choice for calculi in this location [20, 25]. However, the use of URS requires regional or general anesthesia, and is associated with greater morbidity and cost, especially if endoscopic laser techniques are used.

Stone composition

Stone composition plays a very important role in determining the success of ESWL. Failures are more likely to occur in treating uric acid and cystine calculi. Although these stones form a minority of ureteral calculi, with the large remainder of patients having calcium-based stones, their identification may preclude treatment with ESWL.

Uric acid stones in the ureter may be difficult to localize with fluoroscopy and ultrasound, despite being easily fragmented with ESWL. Computed tomography (CT) imaging can be used with some confidence to predict the presence of uric acid stones by measurement of Hounsfield units (HU). In general, pure uric acid stones have a lower CT density (<1000 HU) and calcium stones a higher CT density (>1000 HU) [26–28]. Higher stone attenuation on CT (e.g. >750 HU) has also been shown to be associated with poorer fragmentation rates, independent of other factors such as stone size and location [29–32].

Cystine stones are relatively radiolucent and are often refractory to treatment with ESWL, although the degree of resistance is variable [17]. Patients with cystinuria are often identified based on their propensity to develop recurrent stones, which typically occur earlier in life. Some authors have suggested cystine stones are more likely to be refractory to ESWL treatment as they have a smoother contour on plain imaging and higher CT density [33, 34].

Technical factors

Choice of lithotripter

Whilst the principles of ESWL remain unchanged, the evolution of lithotripters in the last three decades has seen the development of smaller machines with less focal point pressure, in order to reduce anesthetic and analgesic requirements. Consequently, second- and third-generation machines have been shown to have inferior stone fragmentation rates compared to the original first-generation lithotripter, the Dornier HM3. The advent of third-generation machines, however, introduced computer monitoring of treatment in addition to dual-modality stone localizing systems. Further advances have also seen increased machine portability.

To the present day, the Dornier HM3 remains the benchmark and reference for ESWL treatment of renal and ureteric calculi. Comparisons to second- and third-generation machines have yielded mixed results, with several studies demonstrating superior stone-free rates with the Dornier HM3 compared to published results for later generation machines [35–37]. Stone-free rates after a single treatment have been reported to be as high as 90% or more [38, 39]. Gerber *et al*. performed a randomized trial comparing three generations of lithotripters, including the Dornier HM3, and demonstrated inferior stone-free rates with the two newer generation machines [40]. Conversely, Tiselius was able to achieve overall stone-free rates of 97% with third-generation lithotripters, with modest retreatment rates [18].

Few studies currently exist comparing the latest fourth-generation machines with the Dornier HM3 for treatment of ureteral calculi. Nomikos *et al*. compared over 300 patients treated for renal calculi with a fourth-generation lithotripter (Sonolith Vision) to a similar population previously treated with the Dornier HM3, and demonstrated comparable results but with lower analgesic requirements [41]. In a similarly designed study, Pemberton *et al*. compared 107 patients with ureteric calculi treated with the Sonolith Vision lithotripter to a similar group treated with a third-generation machine (Dornier Compact Delta). The authors demonstrated superior stone-free and retreatment rates with the fourth-generation machine, with efficacy approaching that of the Dornier HM3 [42].

Delivery of shock waves: rate and voltage stepping

Some urologists tend to deliver more shock waves in a short period of time as a means to improve treatment and anesthesia times for stone fragmentation. In a recent review, however, Weizer *et al*. showed that a shock rate of 60/min resulted in superior stone-free rates compared to 120 shocks/min in calculi of less than 2 cm [4]. A more recent meta-analysis by Semins *et al*. also demonstrated that 60 shocks/min are superior to 120 shocks/min in achieving successful ESWL [43].

Stone fragmentation relies on a combination of two fundamental mechanisms: stress waves, which are dominant in the initial disintegration of stones, and cavitation bubbles, which produce fine fragments and are critical for success of ESWL. However, the formation and collapse of cavitation bubbles may result in unwanted collateral tissue injury; thus, the optimal use of both can improve stone communition and reduce tissue damage [44]. Voltage stepping, which involves initiating treatment at a low kilovoltage (kV) and then gradually increasing power output, has also been suggested as a means to improve stone fragmentation (compared to constant output voltage) based on *in vitro* studies [45]. Using porcine kidneys, Connors *et al.* demonstrated that voltage stepping results in less shock-wave-induced renal injury [46]. However, the authors acknowledged that this effect may have been due to a period of "rest" applied between the ramps of voltage (approximately 3–4 min). Voltage stepping may also allow for improved patient comfort and reduced pain.

In 2010, Lambert *et al*. demonstrated evidence for both improved stone communition and reduced renal injury in a study of 45 patients randomized to either a voltage-escalating treatment regimen or to standard treatment [47]. Stone-free rates following one treatment session at 1month were 81% and 48% for the voltage-stepping and standard treatment groups, respectively. Renal injury was assessed by measurement of urinary microalbumin and β2-microglobulin levels, and both were shown to be lower at 1 week post ESWL in the voltage escalation group, suggesting a degree of reduced renal injury. Also recently, Honey *et al*. investigated the effect of delayed voltage escalation (starting with 1500 shocks at a fixed voltage and then stepping up to a set maximum) to immediate voltage escalation (increase of 1 kV per 10 shocks up to a set maximum) in their randomized study of 160 patients with renal stones. The authors were unable to demonstrate any benefit in stone fragmentation with the delayed escalation technique, which in fact was shown to be inferior [48].

In a small prospective study of 50 patients undergoing ESWL for renal and ureteral calculi, Demirci *et al*. demonstrated a higher stone-free rate at 8 weeks follow-up for patients randomized to a voltage-stepping technique compared to those treated with constant output voltage (80% vs 60%), although this was not statistically significant [49]. Further work needs to be done in order to define an optimal treatment algorithm incorporating starting shock-wave voltage, voltage stepping (immediate or delayed), and shock-wave rate.

Effect of ureteric stenting

Rationale for use

ESWL has traditionally been considered as a challenge for treating impacted upper ureteric calculi, which are more difficult to fragment compared to stones in the renal pelvis. This effect may be explained by the previously mentioned physics of stone fragmentation. As a stone–water (i.e. urine) interface allows spallation and cavitation, stones impacted in the ureteral mucosa have reduced surface area in contact with water. Initially, it was almost routine that urologists would perform stenting prior to ESWL in order to increase the stone–water interface and thus improve stone fragmentation [24].

However, there is now substantial evidence suggesting that stenting prior to ESWL is unnecessary, and does not improve the rate or effect of stone clearance. Some studies have in fact demonstrated lower stone-free rates in stented patients compared with those who were not stented [50, 51].

The AUA Clinical Guideline Panel in 1997 and with the EUA in 2007 did not recommend routine stenting as part of ESWL treatment based on large meta-analyses of available data [17, 24]. A recent review of the literature by Haleblian *et al*. also did not recommend routine stenting prior to ESWL [52].

Very recently, Ghoneim *et al*. performed a prospective trial of 60 patients with obstructive proximal ureteric stones of 2 cm or less randomized to either stenting or nonstenting groups [22]. The authors demonstrated no significant difference in stone clearance, average number of sessions per patient, retreatment rates, and number of shock waves delivered. El-Assmy *et al*. also performed a study of 184 patients with ureteric stones of 2 cm or less in moderately or severely obstructed systems. The authors similarly were unable to demonstrate any advantage in the group randomized to stenting compared to the nonstented group [53]. However, many patients with stents complained of significant stent-related symptoms. Joshi *et al*. retrospectively reviewed outcomes of 82 patients with obstructing ureteric stones managed with percutaneous antegrade nephrostomy prior to ESWL, retrograde ureteric stenting prior to ESWL, and ESWL alone in the acute setting. They found urgent ESWL to be superior to antegrade or retrograde stenting prior to ESWL [54]. Although data are limited, other studies have also suggested that ESWL in the emergency or acute setting for obstructing ureteric stones is a safe and effective means of treatment [55, 56].

Stone manipulation prior to extracorporeal shock-wave lithotripsy

In the 1990s, the practice of pushing stones back into the renal pelvis from the proximal ureter prior to ESWL was widely accepted for uncomplicated calculi. However, in a large study of over 1700 patients, Cass *et al*. demonstrated that such stone manipulation gained little advantage over ESWL treatment of *in situ* proximal ureteric stones [57]. Danuser *et al*. also reported a similar finding in their prospective trial of 110 patients randomized to either *in situ* ESWL treatment or manipulation prior to ESWL [58]. More recently, Varkarakis *et al*. performed a similar randomized trial of 130 patients, but also analyzed financial costs of stone manipulation prior to ESWL. The authors found that although stone-free rates at 1 month were higher in the stone manipulation group, both groups were equal in this regard at 3 months post treatment [59]. Furthermore, the disparity in cost difference was mitigated by extra ESWL sessions required for the *in situ* treatment group, as well as more frequent follow-up and emergency room visits due to the longer times required for stone clearance.

Stent-related morbidity

The potential for significant stent-related discomfort and morbidity has been well-documented when used prior to ESWL [22, 52, 60]. Such symptoms include suprapubic pain, flank pain, dysuria, urinary frequency, and hematuria. Ureteral stents are also associated with bacterial colonization and an increased incidence of urinary tract infections, as well as being prone to encrustation and migration [61–63]. However, despite increased irritative symptoms, there is potential for decreased hospital readmissions and emergency room visits in these patients [60].

The insertion of a stent is also an invasive procedure and can be technically difficult with the inherent risk of ureteral perforation. Increased costs to the patient, such as analgesia or anticholinergics, as well as to treating institutions, such as readmissions for cystoscopic stent removal, can also be significant [64, 65].

Latest developments in stent technology

In recent years, there have been several advances in minimizing the discomfort and morbidity associated with ureteral stenting prior to ESWL of ureteric calculi. Such advances have included the use of novel biomaterials, stent coatings, and drug-eluting technologies to reduce the risk of stone encrustation and infection [66–69]. Other advances have been in minimizing stent-related discomfort, such as intravesical instillation of ketorolac immediately after stent insertion [70]. However, ongoing research is required to show whether these advances will prove consistently superior to currently available stenting techniques.

Patient positioning

Shock waves delivered to ureteric stones may be impeded by the skeletal structure. With a patient in a supine position, transverse processes of vertebrae can occasionally impede shock waves to proximal ureteric stones. For mid-ureteral and distal ureteric stones the pelvic bones can significantly interfere with stone localization and delivery of shock waves, and a prone position for such stones may reduce this problem [71]. Several studies have been performed to improve stone fragmentation by way of altering patient position.

In 2006, Hara *et al*. performed a large study of 734 patients assessing the effect of rotated-supine positions for proximal stones and rotated-prone positions for mid and distal ureteric stones. Although success rates were equal, patients with proximal stones received fewer ESWL sessions and were able to tolerate greater shock-wave intensity when in the rotated-supine position [72]. For stones in the mid or distal ureteric positions, significantly improved stone-free rates were seen in patients treated in the rotated-prone position (Figure 52.2). Similarly Kose *et al*. demonstrated that a "modified prone position" for prevesical stones could significantly improve stone clearance (97.5%) compared to treatment in a standard prone position (89.9%), requiring fewer shock waves to be delivered and fewer repeat ESWL sessions (Figure 52.3) [73]. In their large series of patients treated successfully with ESWL, Tiselius treated 88% of patients with mid-ureteric calculi in the prone position (and 80% of patients requiring retreatment) to achieve an overall stone-free rate of 97.8% [18].

Despite latest generation lithotripters allowing shock-wave treatment with reduced analgesic requirements and light sedation, many urologists prefer ESWL to be performed under general anesthesia. Patients under light sedation are more prone to movement, e.g. due to pain, thus reducing the efficiency of shock-wave fragmentation, which requires effective coupling and the stone to remain at the focal point.

Patient factors

Obesity

Several studies have demonstrated that obese patients, as distinguished by body mass index (BMI), suffer from poorer stone-free rates post ESWL [74, 75]. Increased skin–stone distance can reduce the effectiveness of ESWL, and various aids and techniques may be required to allow stones in obese patients to reach the focal zone of the lithotripter [76, 77]. In a retrospective study of 111 patients with renal calculi, Perks *et al*. demonstrated that a skin–stone distance of 9.0 cm or greater (Figure 52.4) negatively impacted the success of ESWL (79% vs 57%) on their multivariate analysis, independent of stone size, location, and BMI [32].

Sex

The use of ESWL in women of childbearing age has been questioned, due to the ionizing radiation associated with fluoroscopy and the potential effects of shock-wave impulses on ovaries, especially when ESWL is applied to distal ureteric calculi which are within close proximity. Some animal studies have been performed to assess this effect, but have failed to demonstrate any association between ESWL to distal ureteric calculi and reduced ovarian function and fertility [78, 79]. Furthermore, limited small retrospective studies of women of childbearing age, who had previously undergone ESWL, have also failed to demonstrate evidence of fertility problems [80, 81]. Thus, given the lack of high-quality evidence, there are no current recommendations against performing ESWL on women of reproductive age [17].

In men, ESWL to distal ureteric calculi and its effect on gonadal function has also been assessed to a limited extent. One animal study with ESWL aimed at testes of male rats showed temporary histologic changes, but no difference in testicular function, as measured by successful mating with female rats and endocrine measures [82]. Several prospective human studies have been performed comparing spermatic function in men receiving ESWL for distal ureteric calculi to a control group consisting of men with renal or proximal ureteric calculi receiving ESWL. Sperm count and motility have been shown to be reduced post ESWL for distal ureteric calculi, but return to normal values by 3 months [83, 84]. However, one study demonstrated values to be within normal range at 3 months, but still remain lower when compared to baseline and the control group [85]. No

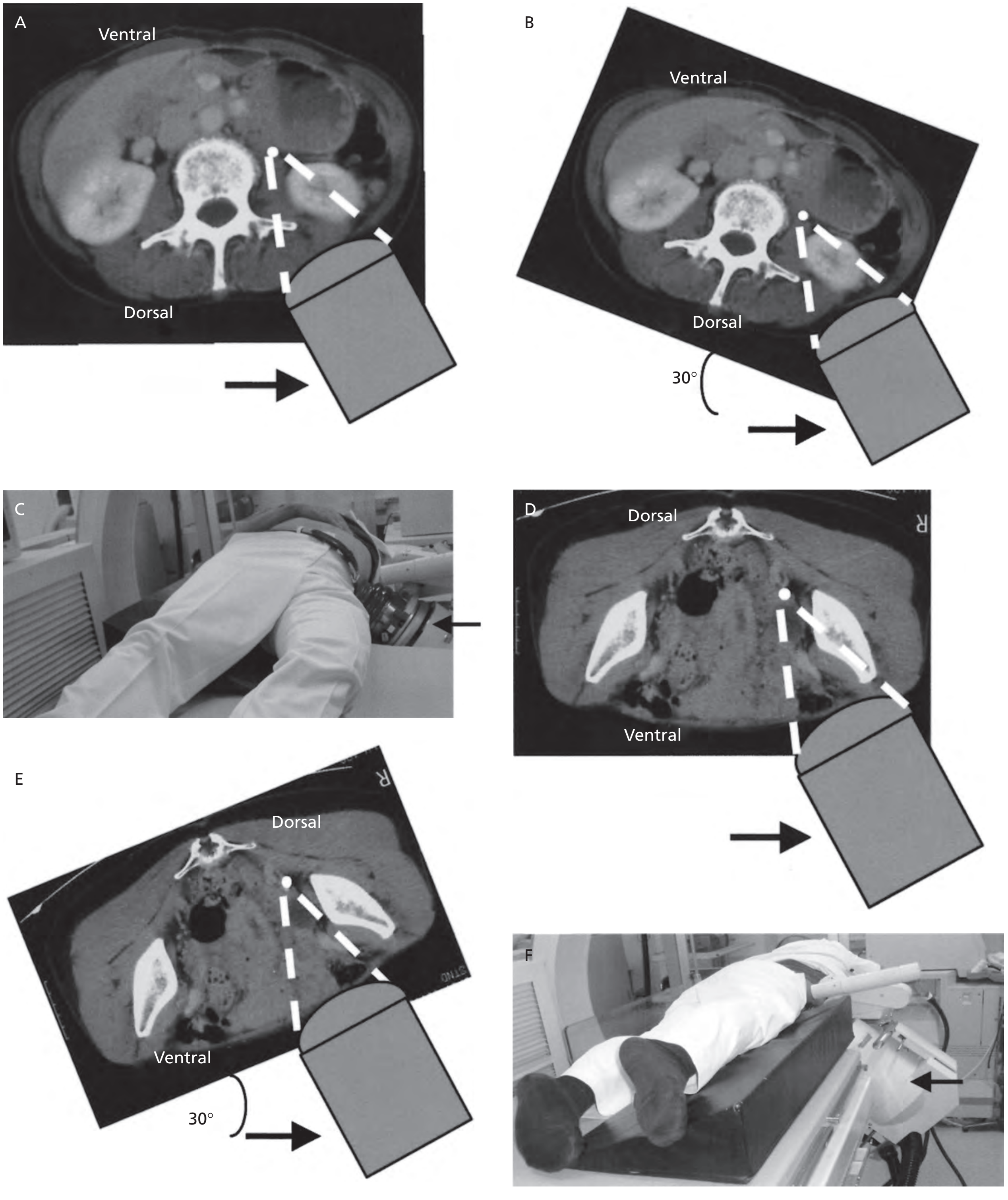
A
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Figure 52.2 (A) Axial CT image of proximal ureteric stone with patient in a supine position. There is potential interference of shock waves from transverse processes of vertebrae. (B, C) Rotated-supine position. (D) Axial CT image of distal ureteric stone and potential interference from pelvic bones. (E, F) Rotated-prone position (reproduced from Hara *et al*. [72], with permission).

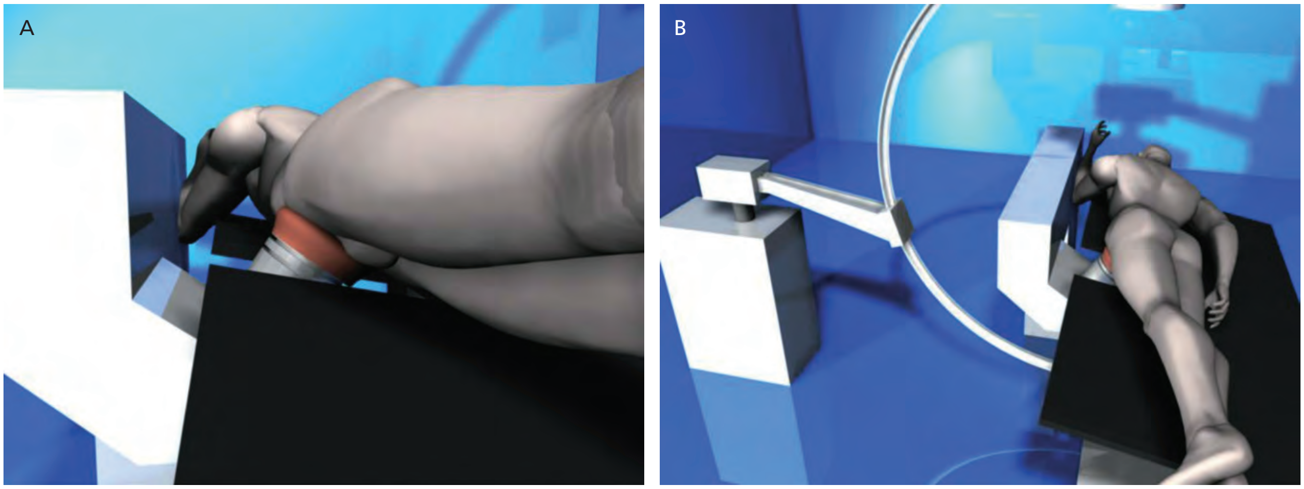

Figure 52.3 (A, B) Computer-generated images of a "modified prone position" (reproduced from Kose *et al*. [73], with permission).

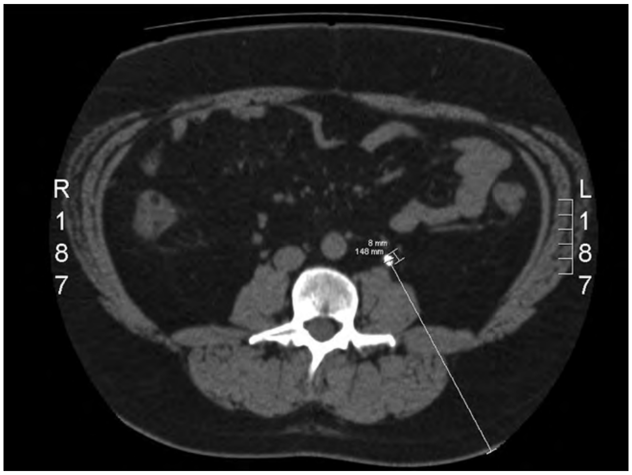

Figure 52.4 Axial CT image of an 8-mm proximal right ureteric stone in an obese patient, with stone–skin distance of 148 mm.

studies have been performed to assess the long-term effect of ESWL on testicular function, but this may be difficult to achieve as infertility can be multifactorial. Again, given the lack of high-quality evidence, men with distal ureteric calculi can be considered safe to treat with ESWL, but other methods such as ureteroscopic stone extraction may be preferable in men with intentions towards conception in the near term post treatment.

Medical factors

Adjunctive medical therapy

Calcium channel blockers and steroids have previously been used to reduce ureteral muscular tone and to decrease mucosal inflammation. Studies of the human ureter have revealed excitatory and inhibitory alpha-adrenergic receptors, with a predominance of alpha-1A and alpha-1D, especially in the lower ureter [86]. This explains the rationale for using alpha-1-adrenergic antagonists to decrease the force and frequency of ureteral contractions.

In recent years, several studies have evaluated the benefit of medical expulsive therapy (MET) with tamsulosin (selective alpha-1-adrenergic antagonist) in improving the passage of stone fragments post ESWL. Early in 2010, Hussein published results from a randomized controlled trial of 166 patients with renal stones. The group treated with tamsulosin and diclofenac had a significantly improved stone-free rate at 3 months (73%) compared to the group treated with diclofenac alone (55%) [87]. Time to stone stone clearance was also improved, with a difference seen at 1 and 2 months follow-up but not at 2 weeks. In 2008, Naja *et al*. demonstrated in a randomized trial of 139 patients with renal stones, earlier stone-free rates, fewer ESWL sessions, and reduced pain in the group treated with tamsulosin, as well as a trend for fewer cases of steinstrasse [88]. A prospective randomized double-blind controlled trial was performed by Bhagat *et al*. in 60 patients with renal and ureteral stones treated with ESWL. Despite small numbers, they demonstrated improved overall stone clearance with tamsulosin compared to controls (96.6% vs 79.3%), with a greater effect seen in larger stones greater than 10 mm [89]. All cases of steinstrasse resolved spontaneously in the treatment group, compared to 25% who required intervention in the control group. In a randomized nonplacebo trial with 55 patients, Agarwal *et al*. were able to demonstrate a significant increase in stone-free status after a single treatment of ESWL in patients treated with tamsulosin (55% vs 25%), despite the smaller power of the study [90]. However, no difference in pain control was seen.

Table 52.1 Summary of recommendations in the American Urological Association/European Urological Association Guideline for the Management of Ureteral Calculi [17].

- All patients with bacteriuria should be treated with appropriate antibiotics, and definitive stone treatment should be delayed until appropriate antibiotic therapy has been administered (level IV evidence).
- In patients with uncomplicated ureteral stones of less than 10 mm and whose symptoms are controlled, a period of observation with or without the use of medical expulsive therapy (MET) is an option (level Ia evidence):
  - These patients should be warned of any attendant risks of MET, such as drug side effects;
  - Such patients should have adequate pain control, absence of infection, and adequate baseline renal function;
  - Periodic follow-up imaging is required to monitor stone position and/or hydronephrosis.
  - Stone removal [e.g. extracorporeal shock-wave lithotripsy [ESWL] or ureteroscopy (URS)] is indicated in patients with failure of stone progression, persistent obstruction, and poorly controlled pain.
- In patients with ureteral stones greater than 10 mm, surgical treatment is generally required.
- For patients requiring surgical treatment for ureteral stones, both ESWL and URS are acceptable first-line treatments (level Ia evidence):
  - Patients must be informed of the available treatment options, expected outcomes, risks and benefits.
- Routine stenting is not recommended as part of ESWL treatment for ureteral calculi (level III evidence).
- Stone manipulation or push back into the renal pelvis is not necessary prior to ESWL, and the limited benefits may be outweighed by the morbidity and costs associated with stent insertion and its removal (level III evidence).

In 2009, a review of four MET trials by Schuler *et al*. supported the use of MET as an adjunct to ESWL, with the evidence showing benefits of tamsulosin and nifedipine over control groups [91]. Similarly, a review performed by Losek *et al*. of five prospective studies using tamsulosin as MET post ESWL for renal and ureteric calculi demonstrated improved stone clearance in two of the included studies (especially for stones >10 mm), as well as a reduction in painful episodes [92]. Conversely, Gravas *et al*. were unable to demonstrate greater stone clearance with tamsulosin in their nonplacebo randomized study of 61 patients, but a significant reduction in the use of nonsteroidal anti-inflammatory medication was found [93]. Very few side effects with tamsulosin were experienced by patients in the above studies, apart from ejaculatory dysfunction.

Contraindications

Despite proven safety in a wide variety of patients, several conditions preclude shock-wave treatment. These include bleeding disorders, pregnancy, congenital renal abnormalities, previous renal surgery, and the presence of concomitant urinary tract infection. Care should also be taken in patients with known impaired baseline renal function.

Clinical recommendations

In the last 5–10 years, there has been a significant increase in the data available addressing the efficacy of ESWL in the treatment of ureteral stones. Although several randomized trials have been performed comparing the efficacy of ESWL to URS stone extraction, there still remains a paucity of well-designed randomized controlled trials. Moreover, the heterogeneity in presenting stone-free rates, retreatment rates, additional procedures, complications, and costs has limited the analysis of the available data.

In 1997, the AUA undertook a large meta-analysis of largely single-arm studies and released guidelines on the management of ureteral stone disease [24]. In 2007, the AUA and EAU joined forces to develop the 2007 Guideline for the Management of Ureteral Calculi (Table 52.1) [17]. This meta-analysis of 244 randomized dual-arm studies and single-arm studies from various clinical series represents the largest, most recent and comprehensive review of available data on the management of ureteral calculi. Two significant changes were observed by the authors of this guideline.

The use of retrograde URS as a first-line treatment for middle and upper ureteral stones had increased significantly in the intervening decade. This can be attributed to the development of smaller caliber semi-rigid and flexible ureteroscopes, the introduction of improved endoscopic tools, such as the holmium : YAG laser, and the increased experience that urologists have of this procedure. Immediate and short-term complication rates, most notably ureteral perforation, have been reduced to below 5%, and long-term complications such as stricture formation occur in 2% or less of cases [94]. The 2007 AUA/EAU study showed overall stone-free rates are very high at 81–94%, depending on stone location, with the majority of patients being stone free after a single procedure [17]. Improved access to the proximal ureter with flexible URS permitted stone-free rates of up to 87% compared to 77% with semi-rigid URS, both of which are comparable to ESWL. Stone-free rates of 86% in the middle ureter were also demonstrated, which was not statistically superior to that seen with ESWL, but follows similar trends to those seen in other randomized trials [20]. Despite the efficacy of URS, the associated need for ureteral stenting and its associated costs, discomfort, and morbidity to patients has biased patient and operator opinion towards ESWL in some cases.

The second notable change in ureteral stone management has been the establishment of MET in facilitating both spontaneous passage of stone, as well as stone fragments post ESWL. As part of the large AUA/EUA meta-analysis, the effectiveness was assessed of MET in accelerating spontaneous passage of ureteral stones and post ESWL fragments [17]. Likelihood of ureteral stone passage was found to be increased by 29% (statistically significant) when tamsulosin was used, compared to nifedipine which increased stone passage by 9% (not statistically significant) [17]. The added effect of corticosteroids was considered small, and thus single-agent therapy with an alpha-blocker currently is recommended.

Although ESWL has been proven to be a safe, well-tolerated, and minimally invasive means of managing renal and ureteral stones, some concerns still exist for the development of long-term complications, such as an increased risk of developing diabetes, hypertension, and impaired renal function. In 2006, Krambeck *et al.* analyzed 19-year follow-up data for 288 patients treated with ESWL for renal and proximal ureteric stones in 1985. Compared to matched controls with stones managed nonsurgically, they found an increased risk of hypertension (odds ratio 1.47), which was strongly related to bilateral treatment, and the development of diabetes mellitus (odds ratio 3.23), which correlated to number of administered shocks and treatment intensity [95]. The development of diabetes may be related to pancreatic islet cell damage from shock waves delivered for renal stones. There was no associated increased risk of development of renal insufficiency. However, in 2009, Makhlouf *et al*. demonstrated no increased incidence of diabetes at 6 years follow-up in their 1869 patients treated with ESWL, compared to matched controls from the National Health and Nutrition Examination Survey database [96]. Similarly, Sato *et al*. were unable to demonstrate an increased incidence of hypertension and diabetes in 772 patients with renal or ureteropelvic junction stones compared to 505 patients with ureteral stones, where follow-up was a minimum of 11 years [97]. In a series of 156 patients with solitary kidneys previously treated with ESWL, El-Assmy *et al*. demonstrated no significant effects on renal function or blood pressure [98]. However, long-term follow-up data were variable, with only 108 patients having follow-up longer than 12 months (range 1–16 years). Due to a paucity of quality long-term data, further large studies with long-term follow-up need to be performed before definitive conclusions can be made about ESWL and potential medical adverse effects.

Currently, there is a need for greater availability of nomograms or other models for predicting the success of ESWL treatment for ureteral and renal stones. Not only would this assist in choosing therapy that is most likely to be successful, but it would allow treating urologists to provide patients with valuable information in the informed consent process. In 2006, Kanao *et al*. performed a retrospective study of 435 patients with renal and ureteric stones in order to develop nomograms to predict stone-free rates at 3 months following single ESWL treatment. The authors found stone length, location, and number to be the most significant factors affecting outcome and adjusted their model accordingly (Table 52.2) [99]. CT imaging characteristics may also prove useful in developing predictive nomograms, by assessing the influence on successful treatment of

Table 52.2 Preoperative nomograms for predicting stone-free rate 3 months after single extracorporeal shock-wave lithotripsy (reproduced from Kanao *et al*. [99], with permission).

	Length (mm)				
	5 or less	6–10	11–15	16–20	21 or greater
Solitary stone					
Calyx	86.1 (68.7–96.2)	72.2 (60.8–81.6)	56.8 (40.0–70.2)	35.1 (21.7–51.6)	23.1 (10.7–37.0)
Renal pelvis	89.3 (97.7–73.6)	77.9 (64.1–88.5)	64.4 (48.4–77.0)	42.7 (23.5–61.4)	29.6 (11.1–49.6)
Proximal ureter	93.8 (86.0–98.3)	86.6 (80.9–91.3)	76.4 (65.2–84.5)	56.7 (36.6–73.3)	42.2 (18.8–63.9)
Mid-distal ureter	92.3 (80.7–98.3)	83.6 (89.7–76.8)	71.8 (59.1–82.2)	51.1 (29.3–71.0)	36.9 (15.9–60.0)
Multiple stones					
Calyx	71.2 (51.4–89.1)	49.7 (36.1–62.4)	33.5 (21.3–46.0)	17.4 (8.4–32.1)	10.5 (3.7–20.0)
Renal pelvis	76.8 (54.7–92.4)	57.6 (37.6–37.8)	41.1 (56.5–23.2)	22.7 (8.1–44.2)	14.3 (3.7–30.5)
Proximal ureter	85.5 (70.7–95.3)	70.8 (56.5–82.5)	55.2 (38.3–71.3)	34.0 (15.1–56.7)	22.5 (6.6–42.8)
Mid-distal ureter	82.4 (65.5–94.7)	65.8 (52.3–77.6)	49.5 (65.4–33.2)	29.2 (12.2–48.8)	18.9 (5.3–37.2)

Parentheses show 95% confidence intervals (%).

factors such as Hounsfield unit-assessed stone attenuation and skin–stone distance [31, 32].

The evidence-based guidelines detailed for the management of ureteric calculi by ESWL are consistent with the findings from an extensive review of the literature by the AUA/EUA Guideline Panel, as well as experience from the authorized groups involved in this review. However, such recommendations may not be applicable to all institutions, as clinical decision-making will need to account for availability of services and equipment, urologist experience and facility with various procedures, as well as costs to patients and hospitals. Furthermore, patient preference is becoming increasingly important in modern medicine, and all patients should be informed of the available procedures, expected outcomes, risks, and side effects to enable an informed decision on an appropriate treatment plan. To illustrate this point, several prospective trials comparing ESWL and URS have demonstrated higher satisfaction rates and patient preference for ESWL [15, 16, 100].

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CHAPTER 53

Complications of Shock-Wave Lithotripsy

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Introduction

It was in Munich, Germany, in 1980 that the first human trials on shock-wave lithotripsy (SWL) were undertaken for the treatment of upper urinary tract calculi [1]. Having demonstrated the reliability and reproducibility of this technology, the Dornier HM3 lithotripter subsequently gained US Food and Drug Administration approval in 1984. SWL rapidly became the treatment of choice for upper urinary calculi due in part to its non-invasive nature, wide application, patient endorsement, and cost-effectiveness [2]. The rapid adoption of SWL was also prompted by the belief the technology was safe with no significant acute or long-term adverse effects. A US cooperative study in 1986 concluded the technology was safe and effective when used to treat upper urinary calculi [3].

While there have been advances in percutaneous nephrolithotomy (PCNL) and retrograde ureteroscopic intrarenal surgery (RIRS) equipment and technique over the decades, SWL is still the choice for the treatment of up to 70% of uncomplicated upper tract calculi [4].

While early reports demonstrated SWL to be safe [1], there is growing awareness that the same shock wave that promotes stone fragmentation and disintegration also injures organs and tissue within the focal area, which can result in an adverse clinical outcome. Complications following SWL can result either from stone fragmentation or the effects of the shock wave on the adjacent tissue.

Complications related to stone fragments

Much of the morbidity associated with SWL treatment results from the fate of the fragmented calculi. SWL can result in incomplete stone fragmentation, residual calculi, steinstrasse, and ureteral obstruction. Several risk factors have been identified as predictors of poor stone clearance rates: stones of greater than 2 cm, stones within dependent or obstructed portions of the kidney, certain stone compositions (mostly calcium oxalate monohydrate and brushite), body habitus, and unsatisfactory targeting of stone [5].

Residual fragments

Newman *et al*. first introduced the concept of clinically insignificant residual fragments (CIRFs) after SWL: stone fragments smaller than 5 mm, not composed of struvite, in asymptomatic patients with sterile urine [6]. These are reported to be present in 12–30% of patients after SWL [7]. It has remained of concern whether CIRFs are really clinically insignificant. In prospective follow-up studies, 22–43% of patients with CIRFs subsequently became symptomatic and/or required intervention [7, 8].

Besides causing symptoms or requiring intervention, residual stone fragments are thought to act as a nidus for new stone formation and to accelerate stone growth. Stone recurrence rates are increased in patients with residual fragments compared to those rendered stone

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free [6]. Streem *et al*. reported in a prospective study of 160 cases that residual fragments of less than 4 mm after SWL were found to increase in size in 18%, decrease in 16%, and remain stable in 42% [7]. Aiming for a stone-free status is even more important in metabolic stone disease. A stone-free state reduces the risk of recurrence and also prolongs treatment interval.

Residual fragments from struvite stones can lead to post-SWL bacteriuria and recurrent and treatment-resistant urinary tract infection (UTI), and become a focus of septicemia.

Steinstrasse

Poor stone fragmentation can also result in ureteric obstruction. A steinstrasse (or stone street) is a term coined to describe a column of fragments obstructing the ureter (Figure 53.1). Coptcoat *et al*. proposed the following classification of steinstrasse: type I is made entirely of fragments of 2 mm or less; type II has a leading fragment of 4–5 mm and a tail of 2-mm fragments; and type III is composed of large fragments [9]. This classification was not widely applied in clinical practice, but the principle of diagnosis and treatment of steinstrasse as described in Coptcoat *et al*.'s 1988 article is still applicable to this day.

Madbouly *et al*. reported an overall incidence of steinstrasse at 3.97% in 4634 patients treated with SWL [10]. Multivariate analysis further identified stone size (>2 cm) and site (renal), renal morphology (dilated system), and shock-wave energy level (>22 kV) as significant risk factors for steinstrasse formation.

The majority of steinstrasse is short and will pass spontaneously, causing only mild discomfort. A larger and longer steinstrasse has the potential to produce partial or complete ureteral obstruction, pain, and secondary infection. Patients with larger steinstrasse require early recognition and prompt management to avoid symptom escalation and progression to sepsis. Acute renal failure and anuria can also complicate cases of bilateral SWL. Fedullo *et al*. reported that among his first 1000 patients undergoing SWL, 27% of those with persistent steinstrasse had silent obstruction on review [11]. This can lead to ipsilateral renal deterioration over time if not identified, and underscores the need for the urologist to closely follow-up patients with plain X-rays, ultrasound, and/or intravenous pyelogram (IVP) to rule out silent obstruction post SWL.

Steinstrasse can potentially be averted with the placement of an indwelling ureteral stent prior to SWL. In selected patients with stone burden exceeding 25 mm, pretreatment placement of ureteral stents reduces the

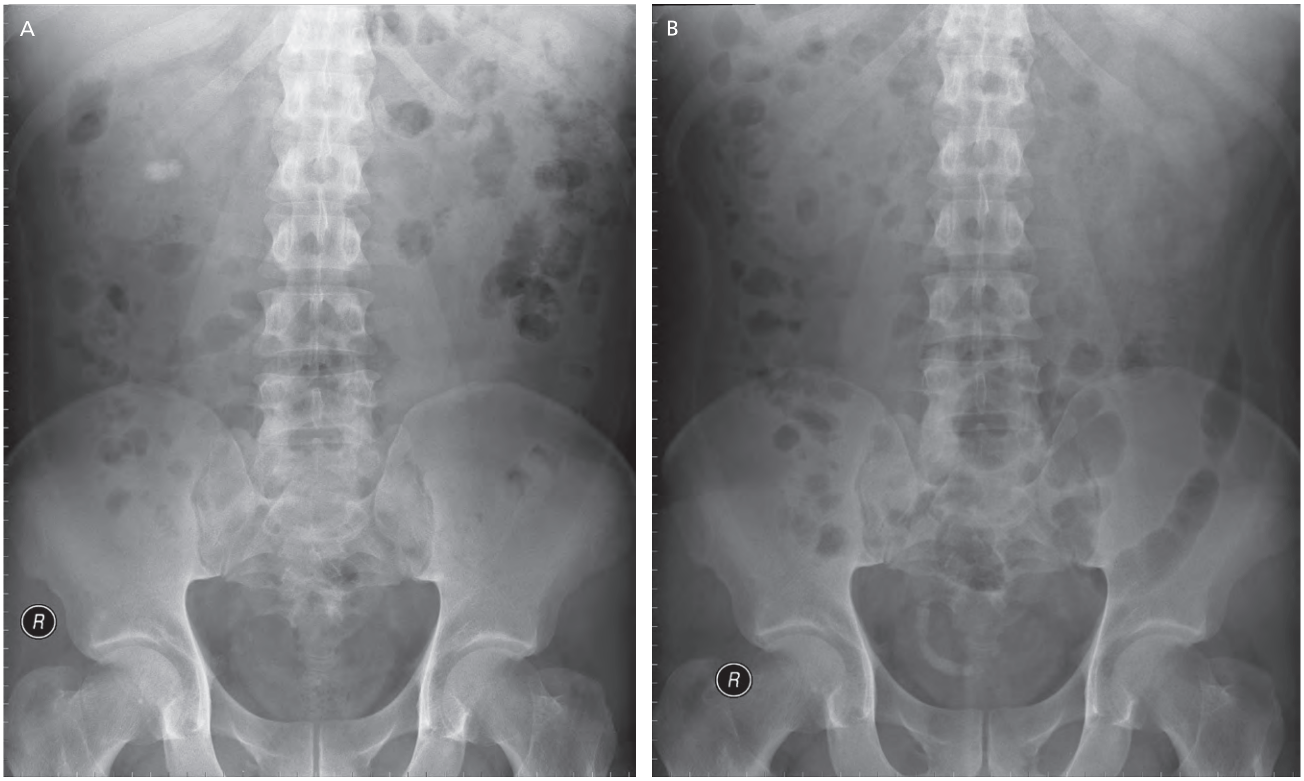

Figure 53.1 Steinstrasse (A) before and (B) after shock-wave lithotripsy.

overall complications and auxiliary procedure rates [12]. Placement of a ureteral stent initially allows passage of urine and gravel through and around it, respectively. With time, the stent induces passive dilation of the ureter and, upon removal, passage of larger fragments can occur through the distended ureter [13]. Fine *et al*. proposed that the urine reflux to the kidney facilitated by an indwelling stent also promotes ureteral peristalsis, which further helps propel urine and gravel into the bladder [14].

Routine pre-SWL ureteral stenting however, is associated with morbidity risks, including gross hematuria, infection, and pain. The degree of discomfort may necessitate removal of the stent [15]. Incidents of stent migration and obstruction are not uncommon [16]. In addition, pre-SWL stenting increases the cost of the procedure and the level of invasiveness [17].

Although ureteral stenting does not prevent steinstrasse or improve stone-free rates, it has a role in preventing obstruction from steinstrasse and should be considered in treating patients with stone size greater than 2 cm [17–19]. In treating stones of less than 20 mm in solitary kidneys, although ureteral stents are associated with more irritative symptoms, their use resulted in fewer hospital readmissions [20].

Infection

The overall reported incidence of sepsis following uncomplicated SWL is less than 1%, rising to 2.7% for staghorn stones [21]. This risk of sepsis is increased in the presence of bacteriuria prior to SWL and especially if there is distal obstruction [22]. The incidence of bacteremia has been reported in up to 14% after SWL [23]. Stone may harbor bacteria even if the urine is sterile [24]. Stone fragmentation can release viable bacteria and preformed bacterial endotoxins that enter the systemic circulation via the microvasculature disruption associated with SWL. Infective complications can include perinephric [25] and psoas [26] abscesses, candidal endophthalmitis [27], and military tuberculosis [28]. Death from sepsis has also been reported [29].

Bacteriuria can develop in 5–16% of patients undergoing SWL with a sterile preprocedure urine culture [30] and 2–3% of these cases will manifest as clinical UTI [30].

The use of periprocedure antibiotics remains controversial. Dincel *et al*. compared the relationship between different stone types and the incidence of UTI in patients undergoing SWL, and found a significantly higher risk of UTI in patients with struvite stones than in those with other types of stones (17.3% vs 2.1%) [31]. There was no significant correlation between the occurrence of bacteriuria and number of stones, size of stones, stone-free rate, or location of the calculi. The authors concluded that prophylactic antimicrobial treatment is only indicated if there is a history of UTI or if infection stone is suspected. Bierkins *et al*. in a prospectively randomized trial of prophylactic antibiotics versus placebo prior to SWL found no difference in the rate of developing post-procedure UTI between the arms (2–3%), and concluded that patients with sterile urine prior to SWL do not need antibiotic prophylaxis [32].

In a meta-analysis of the available literature, however, Pearle *et al*. concluded that a policy of antibiotic prophylaxis prior to SWL in patients with sterile pretreatment urine cultures is efficacious in reducing the rate of post-SWL UTIs (5.7% vs 2.1%). It is also cost-effective when the need for inpatient treatment of urosepsis and pyelonephritis is taken into consideration [33].

While the use of prophylactic antibiotics remains controversial, a good understanding of potential infective complications, coupled with strategies for treatment in the absence of obstruction and bacteriuria, will minimize infective morbidities.

Complications related to tissue injury

Mechanism of tissue injury in shock-wave lithotripsy

Two primary mechanisms have been postulated for SWL-induced tissue damage: cavitation [34] and shear stress [35, 36]. These are the exact same two mechanisms required for stone fragmentation. These SWL-induced tissue injuries are characterized by damage to the vascular endothelium and the rupture of small capillaries. Animal studies have identified several risk factors, including lithotripter parameters (number of shock waves, output energy, pulse repetition rate), and kidney parameters (pediatric or elderly patients, solitary kidney, renal infection, pre-existing hypertension) [37, 38]. In addition, ischemic-reperfusion damage from free radical release after SWL has also been shown in animal studies [39, 40], and this may also contribute to tissue injury.

Acute renal complication

With better understanding of the mechanism of SWL, it is now known that SWL induces acute structural changes to the renal anatomy in most cases. Radiologic changes have been detected using ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and quantitative radionuclide renography in 63–85% of patients within 24 h following treatment with an unmodified HM3 lithotripter [41–44]. Radiologic changes included perinephric hematoma (Figure 53.2), renal enlargement, renal fracture, and loss of corticomedullary junction demarcation. Renal/perirenal

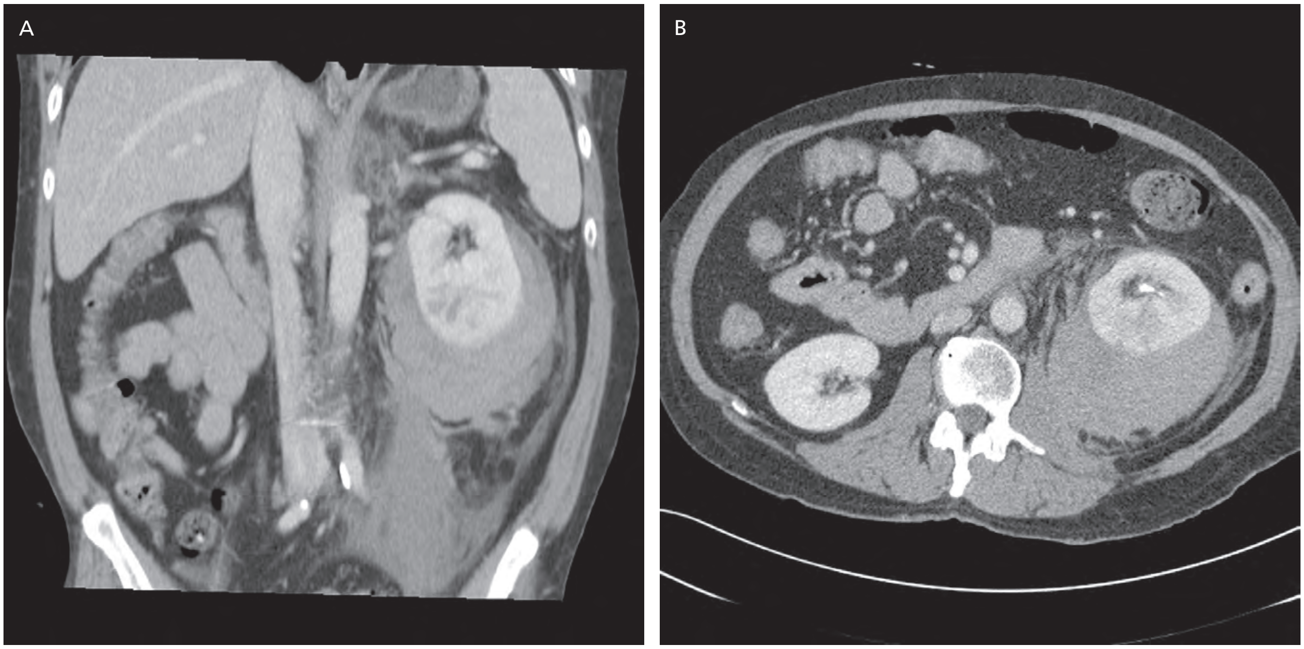

Figure 53.2 (A, B) Post-shock-wave lithotripsy perinephric hematoma.

hematoma and edema are the most common findings. Among the modalities, MRI and CT have proven to be more sensitive than ultrasonography in identifying the post-SWL changes [42].

Bleeding

Hematuria is one of the most common clinical manifestations of post-SWL renal injury. It is observed in patients receiving more than 2000 shocks, is usually of no clinical significance, and can be expected to resolve within 12 h [1, 41]. Petechial bleeding of the skin has been noted in about 10% of patients, while perirenal and subcapsular fluid collection can be detected in 24–32% of patients following SWL [41, 42, 44]. Clinically apparent perirenal hematomas may be expected following 0.6% of SWL treatments [45]. Knapp *et al*. noted that patients with a history of hypertension, particularly those with unsatisfactory control of hypertension, were at increased risk for the development of perinephric hematomas following SWL [42]. Patients on antiplatelet agents were also at increased risk [46]. Other vascular-related risk factors identified include diabetes mellitus, coronary artery disease, and obesity [47]. Age is also a risk factor, with incidence increasing two-fold for every 10 years [48]. Severe cases of hematoma formation can result in irreversible acute renal failure.

Most hematomas can be managed conservatively. Rarely is there a need for blood transfusion or surgical drainage/evacuation for persistent hemorrhage or mass effect. Although some hematomas can persist for months or years, most will resolve within weeks with no long-term sequelae [49].

Acute nonrenal complications

Gastrointestinal injury

Reports on the effect of SWL on the gastrointestinal tract have been few and widely debated. Chaussy *et al*.'s early experience with SWL revealed no injury to isolated intra-abdominal organs [50], including the bowels. It was assumed that shock waves had minimal effect on tissue as they passed through the body [1].

Since then, case studies have reported isolated instances of gastrointestinal perforations [51, 52], ureterocolic fistulas [53], and even a case of gastrointestinal anastomotic dehiscence [54]. A review of the available literature reported the overall incidence of gastrointestinal complications following SWL to be 1.81% [55].

Several cases of clinical pancreatitis have also been observed, along with cases with asymptomatic rises in serum amylase and lactate dehydrogenase levels following SWL [3, 56]. Coptcoat *et al*. reported their experience with 600 consecutive cases of SWL and noted a 10% incidence of prolonged post-SWL ileus requiring intravenous hydration for more than 24 h [57].

Al Karawi *et al*. prospectively studied 40 patients following SWL and revealed gastric and/or duodenal erosions in 80% of them [58]. Sixty percent of the erosions were in the proximal part of the stomach. None resulted in clinical gastrointestinal bleeding. The authors postulated that the larger air–tissue interface and the resultant increased energy dispersal at this interface can account for the high incidence of erosion.

Splenic rupture has also been reported post SWL [59–61].

Cardiovascular complications

Cardiac arrhythmia was a well-described complication following SWL with the first-generation spark plug lithotripters. To overcome this, electrocardiogram (ECG)-triggered, gated SWL was recommended. The reported frequency of dysarrhythmia following ECG-triggered gated SWL with the first-generation lithotripters ranged from 0.3% to 1% [57, 62]. With the later generations of lithotripters utilizing piezoelectric or electromagnetic sources, general anesthesia was no longer necessary and thus nor was continuous ECG monitoring. Fixed-rate shock-wave administration was proposed to be a reasonable option for the treatment of urolithiasis with the later-generation lithotripters, such as the Dornier MFL 5000 lithotripter [63].

Initial experience with piezoelectric lithotriptors found only occasional episodes of dysarrhythmia without ECG triggering [64, 65]. With continuous ECG monitoring, cardiac dysarrhythmia were noted in 20–54% of treated patients [66, 67]. Ungated SWL can be performed but the incidence of cardiac dysarrhythmia increases [68]. Zanetti *et al*. found no significant correlation between the occurrence of dysarrhythmia, the side treated, the number and strength of the shock waves, or the administration of analgesics [69]. Most, if not all. cases can be completed with gating when symptomatic dysarrhythmia occurs. While ungated SWL appears safe, ECG monitoring is still advisable during the procedure in view of the high incidence of dysarrhythmia, as it will allow immediate corrective measures to be instituted as required.

Patients with cardiac pacemakers can undergo SWL, but depending on the type of pacemaker, reprogramming may be necessary [70, 71]. Rate-responsive pacemakers should be programmed to the nonrate-responsive (VVI) mode, and the pacemaker should be at least 5 cm from the blast path. Urologists who treat patients with a pacemaker are advised to obtain clearance for the patients from their attending cardiologist, and have on standby corrective equipment or temporary pacemakers.

There have been occasional reports of aortic aneurysm rupture during SWL [72–74] and rare reports of major venous thrombosis following SWL [75, 76]. Some authors in small studies have demonstrated that SWL can be performed safely in patients with abdominal aortic aneurysms and renal artery aneurysms [77–79], but the issue remains controversial.

Fertility and pregnancy

Evidence from experimental and animal studies have found that SWL has no significant permanent effect on testicular and ovarian function [80, 81]. Pregnancy, however, is an absolute contraindication for SWL. Shock waves lead to fetal damage and death in the late stage of pregnancy in mice [82]. Following inadvertent application of SWL in pregnancy, there have been case reports of successful delivery of babies with no abnormality [83], but these findings do not justify clinical use of SWLin pregnancy [84].

Andreessen *et al*. studied the semen of healthy men post SWL for distal ureteric stone and found a transient reduction in sperm density and motility that recovered after 3 months [85].

Long-term complications

Renal function

The risk of long-term renal deterioration after SWL is a real concern that has been much debated. The renal histologic manifestation post SWL has been well-documented in animal studies. Newman *et al*. reported diffuse interstitial fibrosis, focal calcification, nephron loss, and scar formation in canine kidneys 1 month post SWL [86]. Morris *et al*. demonstrated a correlation between number of shock waves and the size of the resulting scar [87]. In contrast, Chaussy *et al*. reported no histologic abnormality in canine kidneys up to 1 year post SWL [88].

Functional study in humans showed a reduction of glomerular filtration rate (GFR) shortly after SWL, but this normalized after several weeks [89]. However, long-term decline in GFR after SWL has been shown in patients with underlying renal insufficiency (serum creatinine >2 mg/dL) or with a solitary kidney [90, 91]. Evan *et al*. showed that in pigs, existing pyelonephritis potentiates the functional changes induced by SWL [92].

Pienkny *et al*. established the safety of bilateral SWL when they followed up 319 patients with simultaneous SWL for 3.2 years and found no clinical difference in serum creatinine level when compared to a group of 41 patients who underwent staged bilateral SWL [93]. This result was supported by Perry *et al*. who followed up 120 patients with bilateral SWL for 21 months and found no significant change in serum creatinine level from pretreatment level [94].

Liou *et al*. compared 83 patients with a solitary kidney treated with SWL, PCNL, or both for a mean of 4.4 years and found stable renal function between the treatment groups. This implied that both therapies are equally efficacious for preserving renal function when performed in patients with a solitary kidney [95]. Caution, however, is needed in interpreting studies that rely on serum creatinine to estimate renal function status as up to 20% of renal function can be lost without a significant change in the serum creatinine level.

Hypertension

An early retrospective study by Lingeman *et al*. reported that 8.2% of 243 patients treated with SWL were hypertensive on follow-up and required antihypertensive treatment [96]. The mean follow-up was 1.5 years, giving an annual incidence of 5.5%. However, this does not differ much from the 6% incidence of new-onset hypertension in the general population aged between 30 and 60 years old [97]. Also, further retrospective studies by other authors did not reproduce this correlation [97, 98].

To further investigate the association of SWL with hypertension, Lingeman *et al*. retrospectively studied 961 patients treated for stone disease, of whom 80% were treated with SWL. The remainder were treated with either ureteroscopy or percutaneous surgery, and served as the control. The annual incidence of hypertension in the SWL group(2.4%) did not differ significantly from that in the control group (4.0%) [99]. There was, however, a significant rise in the diastolic blood pressure (DBP) in the SWL group, a finding collaborated by Yokoyama *et al*. [100] Lingeman *et al*. then followed up with another set of blood pressure measurements at 4 years post treatment; the results still showed no significant difference in the annual rate of new-onset hypertension in the SWL arm (2.1%) compared to the control arm (1.6%). The DBP remained significantly higher in the SWL arm but with a trend towards baseline in the later years of the follow-up period [101].

The association of SWL with hypertension has also been studied prospectively. Knapp *et al*. studied the changes in the intrarenal vascular resistive index (RI) using Doppler ultrasound and found an increase in the RI in 30% immediately post SWL [102]. When followed up for 3 months, they found a significant and age-dependent increase in the RI in the treated kidney [103]. Of the patients with a post-SWL RI greater than 0.690, 39% developed hypertension. Those with an RI greater than 0.690 showed a 0.8 sensitivity and a 0.7 specificity in predicting arterial hypertension. The authors suggested that RI is useful to identify the high-risk group for arterial hypertension after SWL. Patients aged over 60 years may develop hypertension at a higher rate. Janetschek *et al*. noted a 45% incidence of developing new-onset hypertension in the group over 60 years old when evaluated for post-SWL changes in RI [104].

A recent study from the Mayo Clinic (Rochester, MN, USA) reviewed the charts of 630 patients at 19 years post SWL. When matched for age, sex, and year of presentation, the SWL-treated patients were found to be 1.5 times more likely to develop hypertension than controls who were conservatively managed for urolithiasis [105]. This risk was highest for those treated with bilateral SWL.

Challenges in evaluating the association of SWL with hypertension include difficulty in identifying if the hypertension is the result of the stones, the renal disease resulting in the stone, or the effects of the treatment to remove the stones. Researchers have found that stone formers have higher blood pressure than controls drawn from the general population and matched for age, sex, and ethnic origin [106].

In summary, no randomized controlled study has yet demonstrated a causal relationship between SWL and hypertension. The true cause of hypertension post SWL is probably multifactorial with the renin–angiotensin system playing a part in its development.

Diabetes mellitus

Krambeck *et al*.'s 19-year retrospective review of the long-term safety of SWL also found that SWL-treated patients were over three times more likely to develop diabetes than controls. Of note, these patients were treated with an unmodified Dornier HM3 back in 1985. The risk of developing diabetes was related to the average intensity and number of shocks administered. There was no association with patient's body mass index (BMI) [105]. These findings have yet to be confirmed by other authors. Sato *et al*. performed a similar study but found no increase in incidence of hypertension and diabetes [107].

It was hypothesized that diabetes mellitus resulted from pancreatic collateral injury during SWL. Reports of acute pancreatitis following SWL seem to support this. However, a follow-up study on patients with SWL for pancreatic stones did not provide evidence to support this idea [108]. A prospective study of possible acute endocrine pancreatic injury following SWL of upper tract stones with a third-generation electromagnetic lithotripter by measuring serum pancreatic markers at 24 h also did not detect any acute changes [109]. No conclusions can be made at this point without further long-term prospective study.

Conclusions

SWL remains arguably the safest available surgical modality for treatment of urinary calculi. Although energy required for stone fragmentation can result in surrounding tissue injury, serious acute adverse events are rare, depending on the individual patient's risk factors, lithotripter used, and treatment protocol administered. Long-term complications of SWL are currently still controversial and future prospective studies will hopefully provide the answer in the near future.

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SECTION 5
Stone Management in Urology

CHAPTER 54

Natural History of Stones

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Introduction

Nephrolithiasis is a common problem in the USA and the incidence is increasing; approximately 13% of men and 7% of women in the USA will be diagnosed with a kidney stone at some point [1]. The true prevalence of stone disease is probably underestimated because many stones remain asymptomatic and consequently go undiagnosed [1]. Despite the variety of preventive medical management and intervention tools, nephrolithiasis is largely a recurrent disease with a relapse rate of approximately 50% in 5–10 years and 75% in 20 years [2]

As the prevalence of urolithiasis is increasing, the financial burden appears to be escalating. The economic impact of urolithiasis takes into account not only the direct medical cost of treatment, but also the indirect cost associated with lost work days. The cost of urolithiasis is estimated at nearly US$2 billion annually, representing a 50% increase since 1994 [1]. Given this outlook, a diagnosis of kidney stones has a substantial impact with regard to patient morbidity and healthcare dollars [1].

Pathogenesis of stone formation

Although much is understood about the physical chemistry involved in nephrolithiasis, the inciting factor and sequence of events that lead to the formation of a kidney stone remain elusive. The vast majority of patients are idiopathic calcium oxalate (CaOx) stone formers (accounting for >80% of stones), making this group critical to the understanding of the pathogenesis of nephrolithiasis [3]. Figure 54.1 provides a gross overview of the initiation of stone formation.

At the molecular level, the first step in stone formation is by a process called nucleation, which occurs at a critical level of super saturation. As the crystals form a lattice structure and begin to grow, they unite to form larger stone structures [3]. This evolving concentration cascade of crystallizable substances in stone formation can be described by defining zones of saturation (Table 54.1).

At the macro level, the leading theory to explain the growth of stones is the formation of a Randall's plaque, which is an area of plaque that acts as an ideal site for overgrowth of CaOx to develop into a calculus. To support this theory, Matlaga *et al.* investigated the prevalence of attached stones in CaOx stone formers [4]. In 23 patients, 24 kidneys and 172 renal papillae were examined. Attached renal calculi were detected in 50% of the papillae, and plaque was present in 91% of the papillae examined. Following removal of CaOx stone at the tip of a renal papilla, a significant amount of plaque was observed at the site of the attachment. The finding that half of the CaOx stone formers harbored attached renal calculi supports the hypothesis that the attached stone is an instrumental component in the formation of CaOx stones [4]. Additionally, Kuo *et al.* reported on a series of renal papillary and cortical biopsies at the time of percutaneous nephrolithotomy (PCNL) in a series of stone formers, in which their histologic data provided similar supportive findings for the role of Randall's

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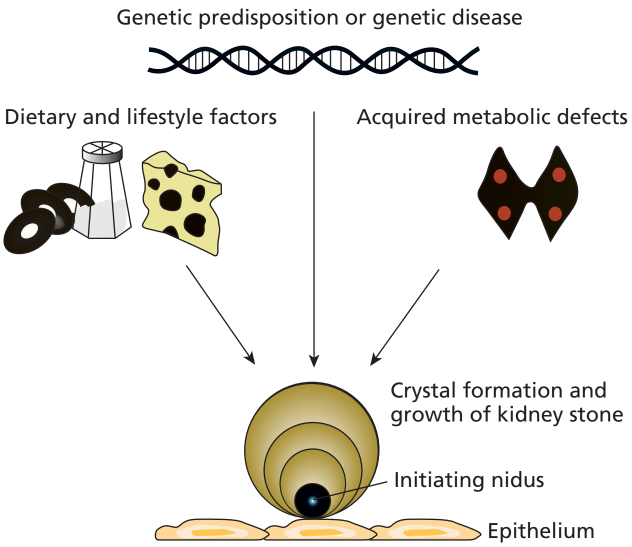

Genetic predisposition or genetic disease
Dietary and lifestyle factors
Acquired metabolic defects
Crystal formation and growth of kidney stone
Initiating nidus
Epithelium

Figure 54.1 Pathogenesis of kidney stones. Using calcium oxalate stones as a model, three categories of factors (genetic, metabolic, and dietary) act in conjunction or in isolation to lead to kidney stone formation. The process needs an initiating nidus on the epithelium, which provides the platform for crystallization and growth (reproduced from Moe [2], with permission).

Table 54.1 Physical chemistry of stone formation (reproduced from Miller *et al*. [3], with permission).

Zones of urinary saturation	
↑ **Increasing concentrations of crystallizable substances** |	Spontaneous crystal formation occurs Crystals already present may grow Aggregation more likely
	Formation product
	No spontaneous crystal formation Crystals already present may grow Epitaxial growth and aggregation possible
	Solubility product
	Undersaturated No nucleation or growth Dissolution may occur Aggregation possible

plaque in the pathogenesis of stone disease [5]. Figure 54.2 displays the stepwise relationship and interplay among the various factors in creating a stone.

Even though there is a litany of information to support stone formation based on molecular saturation levels in conjunction with both inhibitor and promoter components at different rates, there is a paucity of literature that delineates how quickly these stones grow based on their composition. An interplay exists between many variables that both promote and inhibit stone formation, including renal function, hydration status, diet, saturation coefficients of suspended particles, previous stone history, and urinary constituents and their concentrations. These entities make predictions of stone growth very difficult to ascertain as many assumptions are made even in mathematical modeling. Of all the different types of stones, it appears that struvite stones, based on their infectious nature, form more rapidly compared to patients diagnosed with other types of stones such as CaOx stones.

Imaging

Besides studying the formation of stones, there are studies attempting to use the differences in radiodensity or Hounsfield units (HU) within noncontrast computed tomography (CT) imaging to assist in defining the chemical make-up of stones [6]. Knowing the composition of a urinary calculus can be a key factor in the appropriate management. It may help decide whether the urine should be alkalinized, especially if the stone appears to be a uric acid stone, or if the stone will be amenable to extracorporeal shock-wave lithotripsy (ESWL), or whether PCNL or ureteroscopy (URS) should be considered. However, when the HU values of calcium, uric acid, struvite, and cystine stones were compared, the overlap of ranges precluded accurate identification as the mean values were not significantly different from one another [6]. Early CT studies using a single energy technique attempted to show that the attenuation of stones in CT may provide some information about their composition, but they were only able to distinguish some but not all urinary stones. They concluded that the considerable overlap of attenuation values in single-source CT precluded an accurate differentiation of stones according to their different compositions, and therefore was not helpful in determining the most appropriate treatment modality [6–9]. Motley *et al*. assessed over 100 stone patients on preoperative work-up with conventional noncontrast CT scan imagery and compared the results to the final stone analysis. They noted that the largest difference in HU in separate stone entities was between the mean HU density of calcium (105 ± 43) and uric acid (50 ± 24) stones, with considerable overlap when comparing other varieties of stone [6].

Recently, the dual-energy source CT scanner has been introduced as a possible tool to help delineate stone

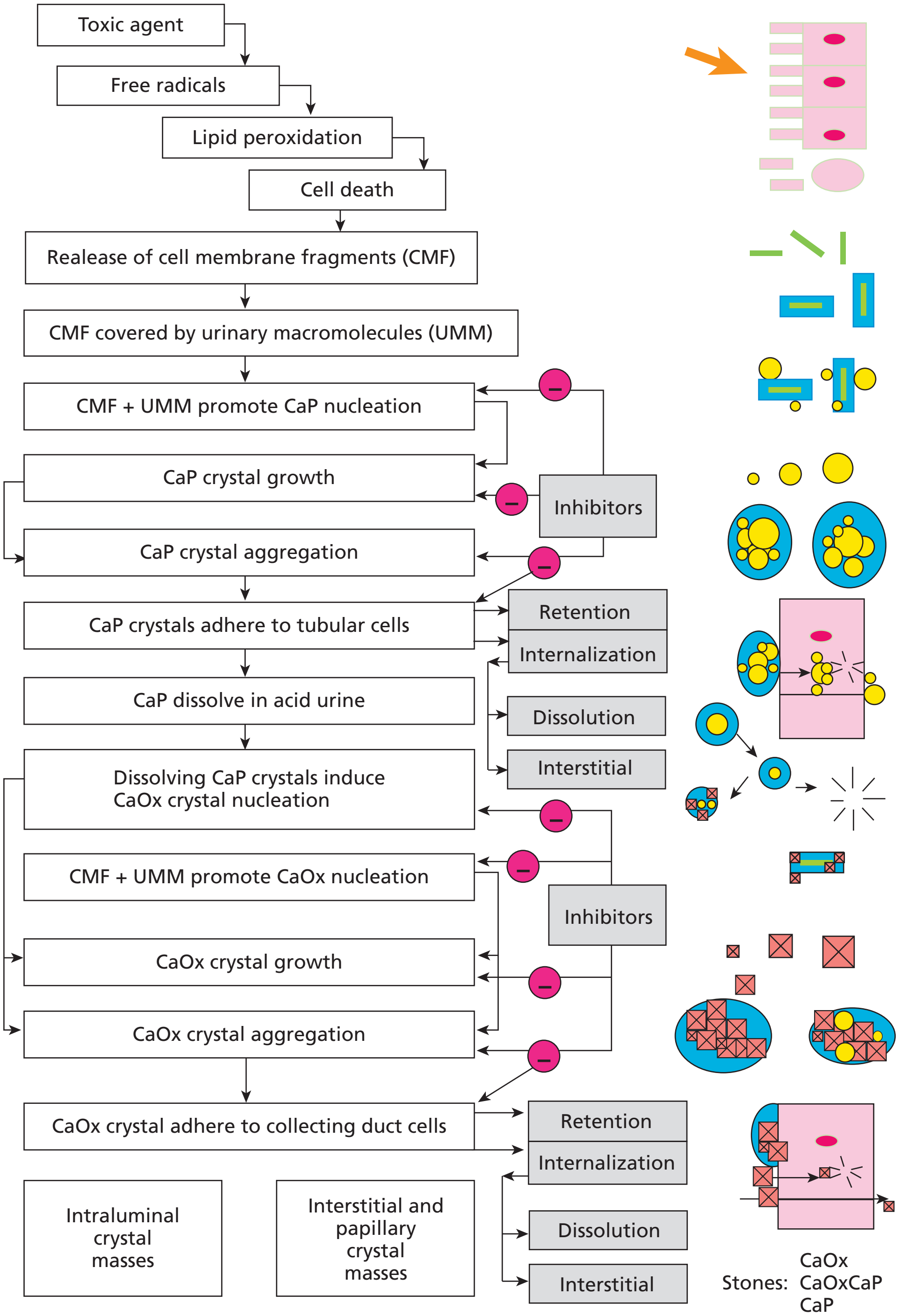

Toxic agent
Free radicals
Lipid peroxidation
Cell death
Realease of cell membrane fragments (CMF)
CMF covered by urinary macromolecules (UMM)
CMF + UMM promote CaP nucleation
CaP crystal growth
CaP crystal aggregation
Inhibitors
CaP crystals adhere to tubular cells
Retention
Internalization
CaP dissolve in acid urine
Dissolution
Interstitial
Dissolving CaP crystals induce CaOx crystal nucleation
CMF + UMM promote CaOx nucleation
Inhibitors
CaOx crystal growth
CaOx crystal aggregation
CaOx crystal adhere to collecting duct cells
Retention
Internalization
Dissolution
Interstitial
Intraluminal crystal masses
Interstitial and papillary crystal masses
Stones: CaOx
CaOxCaP
CaP

Figure 54.2 Stone formation. There is nucleation of crystals by destroyed proximal tubular cells, initiated by lipid peroxidation by free radicals. Next, if there is a deficient activity or concentration of macromolecules that inhibits crystallization, larger crystals form and adhere to tubular walls. Large crystals are then unable to be broken up by macrophages, thus providing a crystal surface for subsequent stone formation on the papillary tip. CaP, calcium phosphate; CaOx, calcium oxalate (reproduced from Tiselius, H.G.. Epidemiology and medical management of stone disease. *BJU Int* 2003;91:758–767, with permission).

composition [10–13]. In assessing the differentiation between uric acid (UA)-containing and non-UA-containing urinary stones, 40 urinary stones were evaluated and analysis indicated that dual-energy CT correctly identified 100% of UA-containing stones, showing that dual-energy CT allows for accurate differentiation between UA-containing and non-UA-containing stones [10]. Using a dual-source CT scan in patients with a history of stones adds an additional tool to the arsenal in treating these patients as the imaging can discriminate between UA stones and other types.

In regards to following patients for postoperative stone-free status, various imaging modalities have been utilized, including ultrasound, plain X-ray, and CT scan. Currently, an unenhanced helical CT is the imaging technique of choice as it has demonstrated a sensitivity of close to 100% and specificity of around 90% in the detection of calculi. Because renal colic frequently affects young adults, with a rate of recurrence of almost 50%, the systematic use of CT at a patient's presentation raises an ethical concern about the repeated doses of radiation being administered [14]. The amount of radiation received during a single noncontrast CT of the abdomen and pelvis during stone evaluation is estimated to result in fatal malignancies in 1 in 1000 patients [15–17].

A single noncontrast CT of the abdomen and pelvis may expose a patient to 20 mSv of radiation. It is estimated that a total of three noncontrast CTs would be approximately equivalent to the radiation exposure of an atomic bomb survivor within 3 km of detonation [15]. Table 54.2 shows comparisons of various radiation exposures due to diagnostic imaging and other environmental sources. One study sought to determine the impact of a low-dose CT protocol (30 mAs) on approximately 125 patients and compared these data to the information obtained with a standard protocol (180 mAs). In patients with a body mass index (BMI) of less than 30, low-dose CT achieved 95% sensitivity and 97% specificity for detecting ureteral calculi. When considering stone size, low-dose CT was 86% sensitive for identifying ureteral calculi of less than 3 mm and 100% sensitive for detecting calculi greater than 3 mm [14]. Recently, ultra low-dose and conventional CT protocols have been investigated for detecting distal ureteral calculi in a cadaveric model [15]. A total of 85 CaOx stones 3–7 mm long were prospectively placed in 14 human cadaveric distal ureters in 56 random configurations. In a study comparing mAs settings at 140 mAs (conventional CT) with 7.5 mAs, the group found that the sensitivity and specificity in detecting ureteral calculi were similar, but with the latter setting the radiation dose was decreased by up to 95% and thus it reduces the risk of long-term secondary malignancies. Table 54.3 shows the radiation doses and exposure reduction at various CT scan settings.

To minimize radiation, physicians have utilized other modalities such as ultrasound. Ultrasound clearly has its limitations. Even though the sensitivity in diagnosing calyceal dilation and ureteral dilation is approximately 73%, in diagnosing a ureteral stone it approaches 19% [18].

Environmental factors

Even though the theory of stone formation and varying imaging modalities is important, a substantial propor-

Table 54.2 Radiation exposure due to diagnostic imaging and other environmental sources (reproduced from Jellison *et al.* [15], with permission).

Diagnostic procedure	Typical effective dose (mSv)	Number of chest X-rays* for equivalent effective dose
Chest X-ray*	0.02	1
New York–London round-trip flight	0.2	5
KUB	0.7–0.9	35–45
Mammogram	3	150
IVP	2.5	125
Upper gastrointestinal examination	3.0	150
Barium enema	7.0	350
CT		
Head	2.0	100
Abdomen	10.0	500
Pelvis	10.0	500
Mean dose in nuclear workers in major studies	20	1000
Atomic bomb survivors 3 km from	50–100	2500–5000
Ultra low-dose abdominopelvic CT	0.95	48

*Anteroposterior film.
KUB, kidneys, ureters, and bladder; IVP, intravenous pyelogram.

Table 54.3 Radiation doses and exposure reduction at various CT scan settings (reproduced from Jellison *et al.* [15], with permission).

Setting (mAs)	Equivalent dose (mSv)	Radiation decrease (%)
140	19	0
100	13	–32
60	8	–58
30	4	–79
15	2	–89
7.5	0.95	–95

tion of the risk factors for nephrolithiasis stems from environmental factors. Of these factors, dietary modification assumes a pivotal and first-line role in treatment, and diet is a subject of much interest in its relation to urinary lithogenesis [19]. The efficacy of dietary regimens has been confirmed by examining the endpoints of urinary chemistry, stone recurrence, or both. Even in instances where there are no prospective trials, some of the physiologic data are strong enough to justify therapeutic recommendations. The dietary components that can be manipulated include intake of fluid, sodium, animal protein, fruits, calcium, and oxalate. Additionally, Borghi *et al.* conducted a randomized trial where they noted a 45% reduction in stone incidence in patients managed with an increase in fluid consumption alone at 5-year follow-up [19, 20].

When dietary modification is ineffective, pharmacologic treatment should be contemplated [2].One example of medical treatment includes the use of potassium citrate. By providing an alkali load, potassium citrate increases urinary pH and citrate, thereby increasing inhibitory activity [21]. The data in favor of citrate supplementation, based on the known effects of citrate to lower the super saturation of calcium salts and inhibit crystal growth and aggregation, remain quite favorable. One randomized trial of potassium citrate supplementation in patients with hypocitraturia demonstrated a reduction in stone recurrence rates of 75% compared to placebo [22]. In a second trial, 64 patients were randomly assigned to receive placebo or potassium–magnesium citrate daily for up to 3 years in a double-blinded design. New calculi formed in 63.6% of subjects receiving placebo and in 12.9% of subjects receiving potassium–magnesium citrate [19].

Stone passage

Many patients with renal calculi will inevitably present to the urologist's clinic symptom free, at which time an observational or "expectant" strategy is often employed [23]. As technology has improved, unenhanced helical CT is used almost exclusively for the diagnosis and treatment of patients with acute ureterolithiasis [24]. When diagnosed, stone size as measured by axial diameter and location within the ureter are suggested to be the most important factors used to predict the likelihood of spontaneous passage [24].

Once diagnosed, it has been shown that asymptomatic stones that pass spontaneously will likely do so early, with about 30% of stones passing in 2 years and decreased passage rates during subsequent years [25]. In regards to time for symptomatic stone passage, the majority of stones pass spontaneously within 4–6 weeks. This was demonstrated by Miller and Kane who reported that of stones less than 2 mm, 2–4 mm, and 4–6 mm in size, 95% passed spontaneously by 31, 40, and 39 days, respectively [26]. American Urological Association (AUA) guidelines, based on a meta-analysis of the literature, indicate the median probability of spontaneous stone passage is 68% for stones less than 5 mm (n = 224), and 47% for those greater than 5 mm and less than 10 mm in size (n = 104) [27].

Medical expulsion therapy (MET) has come to the forefront as an additional adjunct to treatment of patients with stones during their observation phase. Pooled analysis suggests that MET with alpha-blockers or calcium channel blockers augments stone expulsion rates, reduces the time to stone expulsion, and lowers analgesia requirements for ureteral stones of less than 10 mm with and without ESWL[28]. In a 2007 meta-analysis of 11 trials that enrolled 911 patients, ureteral stone passage was 44% more likely with alpha-blocker therapy versus conservative treatment [26, 29]. The theory behind the effectiveness of medical treatment is that the calcium channel blockers inhibit endogenous prostaglandin synthesis and calcium influx, reducing spontaneous dysrhythmic contractions of the human ureter. Similarly, alpha-blockers inhibit contractions of ureteral musculature, reduce basal tone, and decrease peristaltic frequency and colic pain, possibly facilitating ureteral stone expulsion [28].

Natural history of calyceal stones

An understanding of the natural history of calyceal stones is imperative to both the prevention and treatment of stones, despite the fact that the natural history of asymptomatic calculi has not been well documented [30]. Hubner and Porpaczy in 1990 assessed the natural history of calyceal stones and found that when left alone, they were likely to continue to increase in size, resulting in further pain and infection. Glowacki *et al.* studied a cohort of 107 patients to establish the natural history of asymptomatic urolithiasis. Seventy-three of 107 patients (68.2%) remained asymptomatic at a mean follow-up of 31.6 months. A symptomatic event developed in 34 patients (31.8%): spontaneous passage occurred in 16 patients (15%), endoureteral removal was performed in six (5.6%), PCNL in three (2.8%), and nine (8.4%) were referred for ESWL. The cumulative 5-year probability of a symptomatic event was 48.5%. Of the patients who had a symptomatic event, 47% had spontaneous stone passage, while the remainder required intervention [30]. Other investigators have documented similar findings. Moreover, Burgher *et al*. noted that isolated upper pole calculi less than 4 mm in size are significantly less likely to require surgical intervention [23], while mid renal or lower pole calyceal calculi may become symptomatic and thus should be followed with periodic imaging [31]. Additionally, Burgher *et al*. assessed nine patients presenting with pelvic calculi during their study, and these patients had a higher frequency of intervention, stone growth, and observation failure compared with patients with renal calculi in the upper pole that were less than 4 mm. Despite the low sampling size, the conclusion that cannot be overemphasized is that compared to stones located in the upper, middle, or lower pole, pelvic stones should have the most stringent follow-up, as most of these patients (>50%) will require intervention at some point based on growth or symptoms [23].

When stones are seen on repeat imaging, it is difficult to ascertain whether they are newly formed stones or residual stone fragments. Multiple studies have reviewed data regarding stone fragments and their chance of leading to another episode or growth [32–34]. There is no consensus regarding the size of fragment that may be significant after ESWL in terms of later recurrence, stone growth, or subsequent symptoms. Streem *et al*. followed 160 patients with asymptomatic stone fragments of less than 4 mm after ESWL over 26 months: 43% patients had a repeat episode, with 27% requiring intervention. They concluded that the term "clinically insignificant stone fragment" (CIRF), referring to any residual stone after ESWL, is likely a misnomer [35]. One theory is that stone growth may be enhanced after ESWL secondarily to the intervention increasing the surface area of the treated stones [36], potentially leaving a stone nidus that can ultimately result in a symptomatic episode in the future. All attempts should be made to render a patient stone free to avoid the incidence of stone fragments. Stone-free status can be best achieved by selecting the most appropriate treatment alternative for the management of a stone of a particular size, composition, or location.

Staghorn calculi

Despite the discussion regarding the natural history of asymptomatic calculi based on stone location, a particular note should be made about staghorn calculi. These are branched stones that occupy a large portion of the collecting system, and are often referred to as "infection stones" since they are strongly associated with urinary tract infections (UTIs) with urea-splitting organisms. These stones can grow rapidly over a period of weeks to months into a staghorn or branched calculus that involves the entire renal pelvis and, if left untreated, can lead to deterioration of kidney function and endstage renal disease. In a retrospective study of 177 patients with staghorn calculi who were followed over 7 years, renal deterioration occurred in 28% of patients, significantly adding to patient morbidity [37]. Additionally, patients with untreated staghorn stones experienced an increased mortality rate, suggesting that once a staghorn calculus is diagnosed, intervention is warranted. Untreated complex staghorn calculi may result in recurrent UTIs, xanthogranulomatous pyelonephritis, and/or sepsis, and may be better served with a nephrectomy to prevent further patient morbidity, especially when the contralateral kidney is normal [38].

Role of intervention in asymptomatic calculi

Because the natural history of asymptomatic calculi is only poorly understood, judgment regarding the timing and type of pre-emptive intervention must be made without adequate evidence at times, as a period of observation may lead to more invasive procedures in the future for the patient [31]. Despite the prevalence of stone disease in our society, there exists minimal evidence on the optimal intervention with regards to type and timing. Whether prophylactic treatment of asymptomatic stones is justified or not remains to be determined.

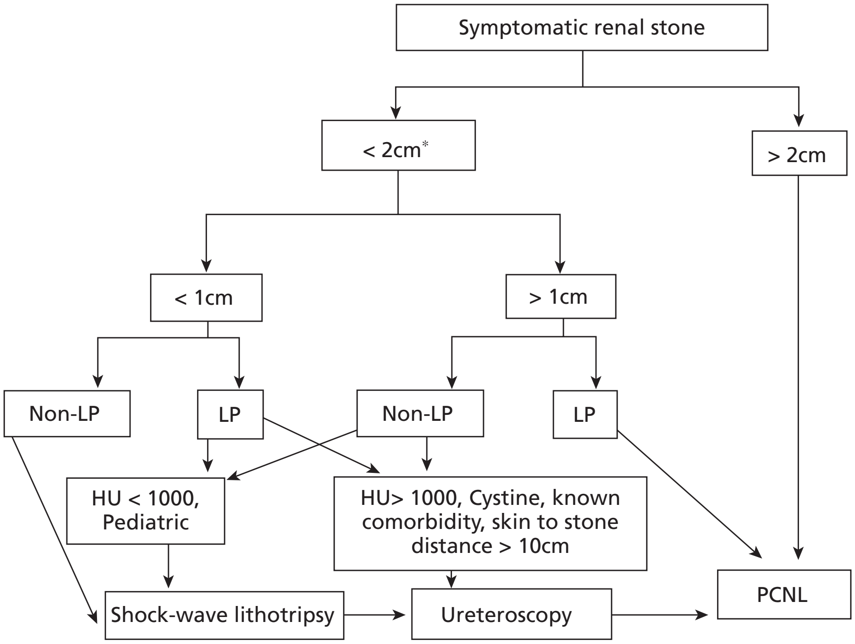
Despite the body of literature that exists regarding small calyceal stones, there are many variables that influence the decision to intervene. These variables include parameters such as stone size, possible stone composition, symptoms, and location. Burgher *et al.*'s retrospective study evaluated the natural history of asymptomatic calculi and the risk of progression of disease in 300 male patients with an average age of 62.8 years over a period of approximately 3 years. In their experience, 77% of patients experienced disease progression, with 26% requiring surgical intervention. Disease progression was defined as nonmedical intervention, development of pain during follow-up, and net cumulative stone growth. Those patients with a stone greater than 4 mm on presentation were more likely (26%) to fail observation than patients with smaller solitary calculi. They also found that isolated upper pole calculi of less than 4 mm have lower rates of failure with observation, as none of their patients required intervention over approximately 3 years [23]. Based on their observations, it would appear that observing stones less than 4 mm in the kidney may be warranted, especially if a stone of this size is located in the upper pole and the patient remains asymptomatic. Asymptomatic stones found in elderly patients and/or those with significant comorbidities may be best managed expectantly, with close observation, utilizing periodic ultrasonography to follow renal calculi for rapid growth or change in location. Certainly, elderly patients with symptomatic stones should be managed similar to a young and otherwise healthy patient with a symptomatic stone.

While most calyceal stones can be treated with ESWL, it is important to be aware of the factors that adversely affect ESWL results. Large stone burden, stones that fragment poorly with ESWL, or stones in particular anatomic positions may be better approached by PCNL or URS. Figure 54.3 demonstrates an algorithm to consider when treating a renal calculus. The most recent AUA guidelines published in 2007 and reviewed in 2009 described the efficacy of intervention strategies for managing ureteral stones based on size of the stone and location within the ureter (Table 54.4). Knowledge of the factors affecting stone clearance will allow the physician and patient to choose the most appropriate treatment approach to achieve maximal stone clearance [31].

Of the trends in distribution of surgical treatment modalities in various databases, ESWL remains the most commonly performed procedure for upper tract stones, followed by URS and PCNL. In analysis, the distribution of procedures in the mid to late 1990s was as follows: ESWL 49–54% of procedures, URS 40–42%, and PCNL 5–6% [1]. Whether achieved by open surgery, PCNL, URS, or ESWL, the common goal remains complete stone clearance, thereby decreasing the risk of stone recurrence and regrowth [31]. At the clinical level, practitioners must consider the concept that urolithiasis is a manifestation of an underlying metabolic or physiologic defect rather than an entity in and of itself, and seek to manage these patients based on this philosophy.

Conclusions

The incidence and prevalence of nephrolithiasis within the USA and throughout the world continues to increase, leading to patient morbidity, need for intervention causing lost productivity, and elevated healthcare costs. The clinical assessment of the stone should be pathophysiology oriented in an attempt to unveil features more proximal to the underlying cause. Dietary and



*if bleeding diathesis, morbidly obese, URS; if ureteropelvic junction, caliceal tic, percutaneous nephrolithotomy (PCNL)

Figure 54.3 Recommendations of treatment of renal stones by stone location (Reproduced from Wen, C.C., Nakada, S. Treatment selection and outcomes: Renal calculi. *Urol Clin North Am* 2007;34:409–419, with permission).

Table 54.4 Comparison of stone-free rates between shock-wave lithotripsy (SWL) and ureteroscopy (URS), based on size and location within the ureter (reproduced from Preminger *et al*. [27],with permission).

	AUA/EUA Ureteral Stones Guideline Panel Stone-free rate: primary treatments or first treatment			
	SWL		URS	
Overall population	G P	Medium (%) (95% CI)	G P	Medium (%) (95% CI)
Distal ureter	50 6981	74 (73–75)	59 5922	94 (93–95)
<10 mm	17 1684	86 (80–91)	13 1622	97 (96–98)
... >10 mm	10 966	74 (57–87)	87 412	93 (88–96)
Mid ureter	31 1607	73 (66–79)	30 1024	86 (81–89)
<10 mm	5 44	84 (65–95)	5 80	91 (81–96)
... >10 mm	2 15	76 (36–97)	5 73	78 (61–90)
Proximal ureter	41 6248	82 (79–85)	46 2242	81 (77–85)
<10 mm	14 886	90 (85–93)	9 243	80 (73–85)
... >10 mm	11 293	68 (55–79)	8 230	79 (71–87)

G, number of groups/treatment arms extracted; P, number of patients in those groups.

environmental factors play a major role in the development of renal calculi, and may assist in the prevention of future stones once the etiology is determined. Recommendations for intervention should be made to best benefit the patient with regards to invasiveness, complication, and recurrence.

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CHAPTER 55

Initial Choice of Therapy in the Urinary Stone Patient

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Introduction

Urolithiasis is a prevalent condition, afflicting 5–10% of the population, at an estimated annual cost of US$2 billion to the American healthcare system [1]. As the front line in managing stone disease, the urologist is armed with numerous tools to manage a patient presenting with a urinary stone. This chapter will focus on adult patients with "normal" renal anatomy, as stones in aberrant urinary systems are discussed elsewhere in Chapters 61–64. Since the focus is elective stone management, patients presenting with sepsis, renal failure, or intractable pain are not discussed, as these situations dictate urgent urinary tract decompression with either ureteral stenting or percutaneous nephrostomy.

The prime modalities discussed are shock-wave lithotripsy (SWL), ureteroscopy/ureterorenoscopy (URS), percutaneous nephrolithotomy (PCNL), medical expulsive therapy (MET), and observation. In recent years, there have been numerous advances in the technology applicable to URS and PCNL, as well as growing evidence of the effectiveness of MET, all of which have altered the approach to the stone patient. Therapeutic decisions in this chapter will be guided by stone location within the urinary system, stone size, stone characteristics and composition, and special factors such as urinary tract anatomy, patient body habitus, and patient comorbidity.

Ureteral stones

The patient with a ureteral calculus can be managed with a variety of modalities, ranging from observation and MET to surgical interventions with URS, SWL, and occasionally PCNL for large proximal stones. Stone size, location, and composition are critical factors in the initial approach to a ureteral calculus. The use of cross-sectional imaging in the diagnosis and management of urinary stone disease is widespread. In recent years, efforts have been made to predict stone composition with computed tomography (CT), and subsequently to guide treatment, especially SWL. Stones with Hounsfield unit measurements over 750–1000 appear to have lower SWL success rates than stones with lower attenuation [2].

Distal ureteral stones

Stones presenting in the distal ureter are amongst those with the highest rate of spontaneous passage [3]. Once they have traversed the proximal and mid ureter, the ureterovesical junction (UVJ) remains a common site for stones to become impacted and obstructive (Figure 55.1A). The size of the calculus is critical to the assessment of potential for spontaneous passage versus the decision to intervene. Generally speaking, smaller stones that are further along the ureter have a greater chance of spontaneous passage than larger stones in a more proximal location. Pooled data presented in the American Urological Association (AUA) ureteral calculus guidelines from 2007 suggest a 68% rate of stone passage for ureteral calculi under 5 mm in size(based upon 224 patients from five studies), and for stones of 5–10 mm in size there is a 47% rate of passage (based

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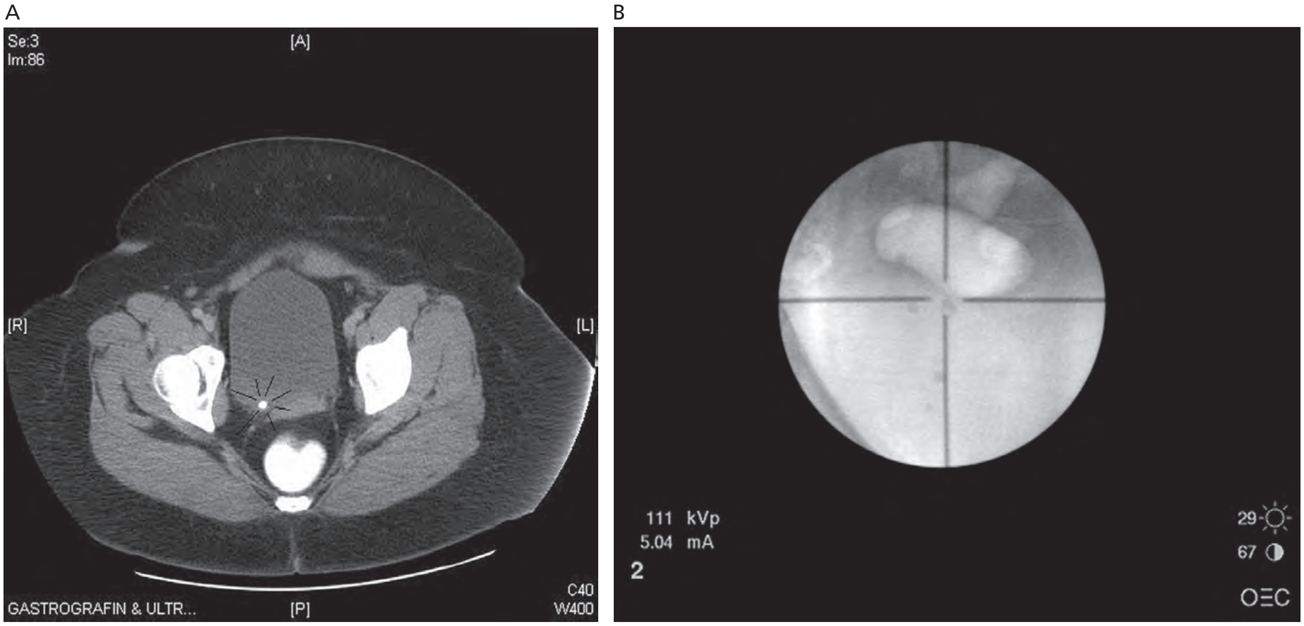


Figure 55.1 (A) CT of right distal ureteral calculus at the ureterovesical junction (demarcated by lines). (B) Fluoroscopy of right distal ureteral stone localized at the F2 focal point for shock-wave lithotripsy.

upon 104 patients from three studies) [3]. Supportive data exist from an observational study of 75 patients with ureteral calculi observed for spontaneous passage [4]. Amongst this cohort, stones greater than 4 mm in size required intervention 50% of the time [4]. Stones smaller than 2 mm in size passed on average at 8 days; stones of 2–4 mm passed on average at 12 days; and stones greater than 4 mm passed on average at 22 days. Of stones that did not require intervention, 95% passed within 30–40 days [4].

A trial of MET is warranted in nearly all patients with uncomplicated presentation of distal stones of 1 cm or smaller. Two meta-analyses have examined the role of both alpha-antagonists and calcium channel blockers (CCBs) to increase the rate of stone passage, as well as to hasten stone passage, and most of the existing data are for stones averaging over 5 mm in size [5, 6]. Both studies support an increased rate of stone expulsion with alpha-blockers and CCBs. The review from Hollingsworth *et al*. suggests a 65% increased rate of stone expulsion with either agent, and the number needed to treat (NNT) to lead to one additional stone expulsion was 4 [5]. A study from the emergency medicine literature, pooling data from 16 alpha-blocker studies and nine CCB studies, shows a 59% greater rate of passage with alpha-blockers and a 50% greater rate of passage with CCBs [6]. The NNT with alpha-blockers was 3.3 and for CCBs 3.9 [6]. The complication rate for alpha-blockers was 4% and for CCBs 15%. Based upon their own analysis of the data, the AUA suggests alpha-blockers are the preferred agent for MET [3]. Although most studies with alpha-blockers investigated tamsulosin, equivalent efficacy has been seen with terazosin and doxazosin as well [7].

If a trial of MET fails, there are data to suggest an additional trial of MET is warranted in select patients, with a subsequent increase in the rate of spontaneous stone passage [8]. If this is ultimately unsuccessful, then surgical therapies become appropriate. In the distal ureter, both SWL and URS are highly efficacious.

Pooled data from thousands of patients in the most recent AUA ureteral stone guidelines provide a robust source of outcomes data for both URS and SWL on distal ureteral stones (Figure 55.1B). Based upon nearly 7000 patients who underwent SWL and 6000 who underwent URS, the overall success rate for SWL is 74% in the distal ureter and 94% in the proximal ureter . Distal stones of 1 cm or smaller had an 86% clearance rate with SWL and 97% with URS, and those greater than 1 cm were cleared at rates of 74% and 93%, respectively [3]. Overall, these rates are very close, and clearly both modalities afford an excellent opportunity for stone eradication in the distal ureter. Based upon this analysis, the average patient undergoing SWL for a distal ureteral stone requires 0.37 adjunctive procedures for stone clearance [3].

A Cochrane Review was performed of the small number of randomized trials comparing URS and SWL for ureteral stones. These studies were not limited to distal stones, though four of the five studies included were based on distal stones alone. This review reported a slightly higher success rate for URS, a slightly higher rate of adjunctive procedures needed with SWL, and a slightly lower rate of complications with SWL [9].

Given these factors, how is the initial choice of surgical management in distal ureteral stones best approached? Patient preference and comorbidity, and surgeon preferences must be taken into account in order to decide on the optimal treatment plan. From an anesthetic standpoint, URS can generally be performed under either spinal or general anesthesia, while SWL can usually be performed with sedation. Availability of appropriate equipment may be a factor, as not all centers have ready access to various technologies "on demand," potentially leading to unacceptable delays with one modality. Finally, there remains some concern in women of childbearing age that SWL may be harmful for fertility, and thus it is not suggested for use in the distal ureter in this patient population [10].

Common side effects of SWL include incomplete stone fragmentation or passage, necessitating additional procedures. Patients with a propensity to hemorrhage or on anticoagulants are not candidates for SWL unless these can be stopped. URS entails its own set of risks, including injury to the ureter, such as perforation or stricture, and proximal migration of stone fragments, though serious complications do occur in less than 5% of patients in modern series [11]. In addition, although not all urologists use stents after routine URS, many do and these can contribute to substantial postoperative morbidity.

Given this information, it seems apparent that a trial of MET is appropriate in virtually all patients with uncomplicated distal ureteral stones. If MET fails, surgical therapy may be required, and URS affords a slightly higher success rate than SWL, though it is associated with a higher rate of complications. Overall, the choice of URS or SWL for a distal ureteral stone lies with the available expertise and equipment, and with the patient after an informed discussion of the risks and benefits of each modality. Armed with the knowledge that both modalities lead to high rates of stone clearance, additional factors such as the potential need for stenting, type of anesthetic used, and complication profile of each procedure can be used to guide the choice of therapy.

Proximal and mid-ureteral stones

Optimal management of these stones depends heavily upon the size of the calculus in question. As described above, larger and more proximal stones are associated with a lower rate and longer time to spontaneous passage than smaller and more distal stones [3, 4]. Management of mid- and proximal ureteral stones is slightly different from that of distal stones, with the largest difference being the lack of evidence for MET in mid- and proximal ureteral stones, as this has not been specifically tested. Operative intervention consists primarily of either SWL or URS, though there is a select role for antegrade approaches to large proximal calculi.

Nonetheless, observation may be a reasonable first-line approach in patients with a small mid- or proximal ureteral stone. If the calculus migrates distally, then MET obviously becomes a treatment choice. Assuming the stone does not appropriately progress, or the patient is otherwise unable to tolerate continued observation, then surgical therapy is appropriate.

Once again, pooled data from multiple studies are provided by the recent AUA guidelines delineating outcomes in the management of proximal and mid-ureteral stones. For stones in the mid ureter, pooled data on 1600 SWL patients and 1000 URS patients is available; SWL had a 73% success rate and URS an 86% success rate [3]. When stratified by size, there is essentially equal stone clearance for stones greater than 1 cm in size, with rates in the 76–78% range. Stones of 1 cm or smaller have an 84% clearance with SWL and 91% with URS [3]. The rate of secondary procedures is slightly higher when SWL is used to manage mid-ureteral stones than when URS is, especially for stones of greater than 1 cm in size. Nearly 1.3 procedures per patient are needed when SWL is used as a first line treatment option with mid-ureteral stones of 1 cm or smaller, and 1.76 procedures per patient are needed for clearance with stones of greater than 1 cm in size [3]. When URS is utilized, 1.04 procedures per patient are needed to achieve stone clearance [3].

Some general issues with the management of mid-ureteral stones with SWL arise, because the structures of the bony pelvis can interfere with visualization and treatment of the stone (Figure 55.2). In some lithotriptors, a prone position must be used to assure the stone is in the ideal position for treatment.

Regarding URS for the mid-ureteral stone, traversing the iliac vessels may sometimes present significant challenges, though the use of flexible scopes and instruments usually minimizes this issue. Proximal stone migration is possible, though usually does not present significant difficulties if the surgeon is proficient with flexible URS.

As with distal stones, a similar decision-making process is undertaken for mid-ureteral stones. The relatively less invasive nature of SWL, somewhat lower rate of success in the mid ureter, and the possibility it can be performed with sedation with lower risk, must be weighed against the greater efficacy and invasiveness of URS.

For proximal ureteral stones of greater than 1 cm in size, or for stones of 1 cm or less that have failed a period of observation, the urologist must decide between URS, SWL, and antegrade approaches to the stone, balancing optimal stone clearance against morbidity.

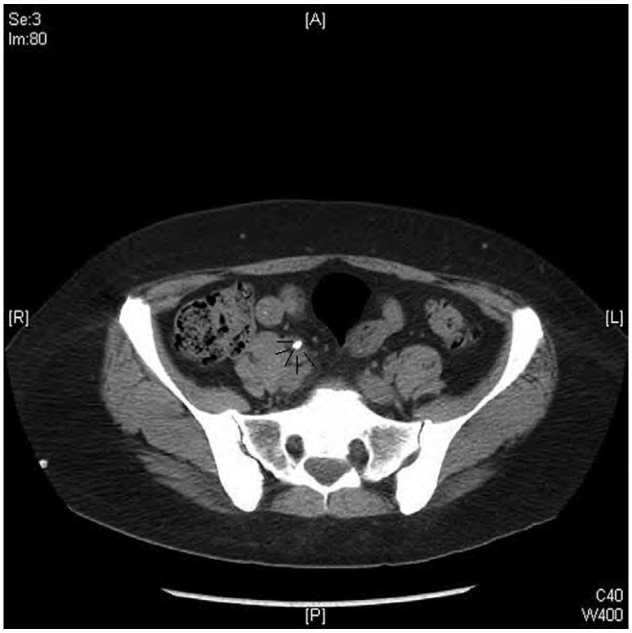


Figure 55.2 CT of right mid-ureteral stone (demarcated by lines). Note the presence of the sacrum and iliac bones posterior, which can interfere with shock transmission.

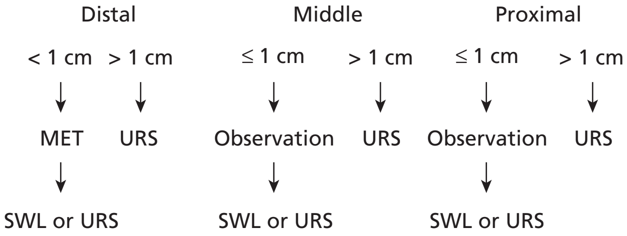


Figure 55.3 Ureteral calculi: optimal initial management strategy. MET, medical expulsive therapy; SWL, shock-wave lithotripsy; URS, ureterorenoscopy.

Overall, success rates for single procedures in the proximal ureter are slightly lower than in more distal locations. Based upon the pooled data in the most recent AUA guidelines, both SWL and URS are associated with roughly 80% success rates [3]. When calculi are 1 cm or smaller in size, SWL has a slight advantage over URS in terms of stone clearance (90% vs 80%); however, when stones are more than 1 cm in size, SWL is associated with a clearance rate of 68% and URS of 79% [3]. Furthermore, once stones over 1 cm are treated, there is a greater need for adjunctive procedures with SWL. For proximal ureteral stones of over 1 cm in size, the average patient requires 1.5 procedures for clearance with SWL as opposed to 1.07 with URS [3].

A recent meta-analysis of SWL versus URS for proximal calculi came to similar conclusions as the AUA guideline panel. The study confirmed that both modalities are effective, with essentially equivalent outcomes for stones of 1 cm or smaller in size [12]. For stone sizes over 1 cm in size, a preference for URS was noted, given its 6% higher stone-free rate [12]. Complications were minimal in the SWL patient; the ureteral stricture rate was roughly 2% in this review [12].

An additional consideration to aid in selecting optimal initial therapy for proximal ureteral stones focuses on the costs incurred with treatment. A cost analysis from Lotan *et al*. shows that URS is less costly than SWL for proximal stones when performed primarily [13]. When considering the higher rate of adjunctive procedures for SWL compared with URS, the cost differential is even greater and is something to potentially consider when deciding how to approach the patient with such a stone [13].

In select cases of very large stones in the proximal ureter, or stones which are heavily impacted and do not permit retrograde access, a patient can be offered an antegrade procedure for clearance [14]. Both rigid and flexible nephroscopy can be used to approach the UPJ and proximal ureter, with appropriate instrumentation to allow a high success rate. In addition, following treatment of the stone, fragments can be removed via the percutaneous tract, obviating the need for passage. The percutaneous approach is used much less frequently than either URS or SWL for these stones, so specific data to support the practice or describe complications approaching proximal ureteral stones are minimal. Nonetheless, given the extensive experience with PCNL for renal calculi, this approach is a viable option for the select patient with a proximal ureteral stone.

Summary

The patient with an uncomplicated ureteral stone is best managed initially with either MET for distal stones, or a period of observation for mid- and proximal ureteral stones (with MET if the stones progress down the ureter). If surgical therapy is indicated, URS generally leads to higher stone-free rates than SWL, though is associated with a higher rate of complications and is more invasive. A frank and informed discussion about the risks and benefits of each surgical approach, individual patient factors, and consideration of stone composition, size, and location, are the optimal means of choosing the most appropriate surgical stone therapy (Figure 55.3).

Renal stones

As in the ureter, both stone size and location are critical to the choice of optimal initial therapy in the renal stone patient. Unlike the ureter, where anatomy is generally straightforward and of little consequence for surgical planning, intrarenal anatomy and patient body habitus can play significant roles in deciding which treatment options are best for each patient. Additionally, stone composition is vitally important, as it heavily impacts the outcomes of SWL, in particular.

For renal stones of 1 cm or smaller that are asymptomatic, nonobstructing, and not associated with infection, a reasonable strategy is one of observation. Periodic assessment of the patient for symptoms and the stone for growth with a plan for deferred management is reasonable. Following the stone with kidney, ureter, and-bladder radiography (KUB) and ultrasound at semiannual or annual intervals is a sensible approach: stone progression or the development of obstruction can be readily detected, and compared to CT limits radiation exposure for the patient. In addition, pursuing metabolic evaluation in these patients is prudent and advocated by several authors, in an effort to limit the growth of calculi while under observation [15, 16].

The rate at which these stones become symptomatic is hard to precisely define, as there is only a small body of literature reporting on a paucity of patients with renal stones undergoing observation only. For all patients, the chances of symptoms referable to a renal calculus range from 31% at 2.5 years [17], to roughly 50% at 5 years [16], and to nearly 70% at 7 years [18]. A contemporary cohort of 300 patients, with an average stone size of 1.1 cm, showed a 77% rate of progression (symptoms, need for surgery, or stone growth) over 3 years [19]. Among these patients, 26% needed surgery over that time period [19]. Larger stone burden and more stone episodes were risk factors for symptoms and the need for intervention [17, 19]. One randomized trial of patients with asymptomatic calyceal stones smaller than 1.5 cm in size showed no advantage of performing elective SWL versus a period of observation [20]. The NNT in this trial was 10, and the authors concluded that observation was an appropriate strategy with asymptomatic calyceal stones of less than 1.5 cm in size [20].

Armed with the knowledge that a renal stone has a moderate chance of ultimately causing symptoms and requiring operative intervention, individual treatment plans can be tailored to each patient based on their clinical presentation.

Renal stones 1 cm or smaller in size

Assuming active treatment is sought, there are three options for managing a renal stone up to 1 cm in size: SWL, URS, and PCNL. Initially we will consider stones located outside of the lower pole (Figure 55.4). SWL is still a first-line option for these stones, especially for a stone of low attenuation on CT scan, in an interpolar, upper polar, or renal pelvic location, and in a calyx with a normal infundibulum [15]. Even if the stone is not radio-opaque, ultrasound can be used to help localize a calculus for SWL in the kidney.

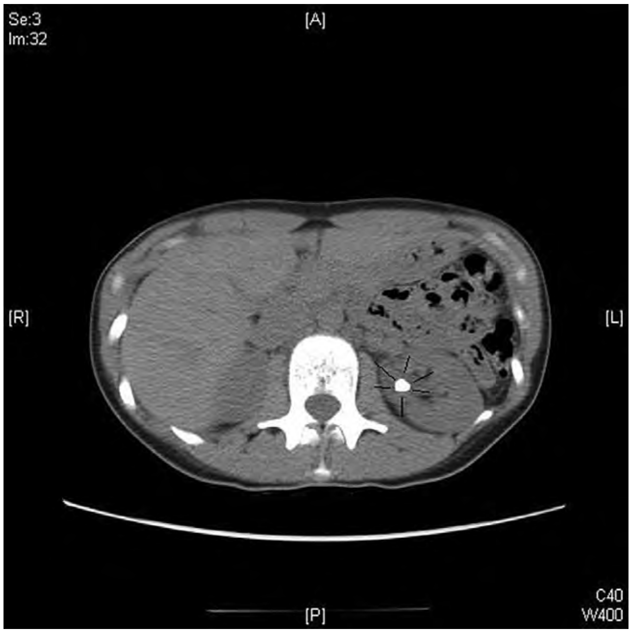


Figure 55.4 CT scan of left renal pelvic stone (demarcated by lines).

Highest clearance is achievable with stones in the renal pelvis, with reported success rates of 80–90% [15]. In upper and interpolar locations, clearance rate is closer to 70% [15]. Although CT does not perfectly predict the composition of stones, stones with higher Hounsfield units (over 750–1000) are less susceptible to management with SWL, and this is a reasonable means of stratifying treatment [3, 21, 22]. Additionally, body habitus in terms of the skin–stone distance is a critical factor in appropriate patient choice for SWL, with a skin–stone distance of over 10 cm associated with poorer outcome for that procedure [21, 22].

URS is a reasonable choice for many renal stones, as modern ureteroscopes can reach the entire collecting system and displace a stone to a readily accessible location for lithotripsy or basket removal. This achieves equivalent outcomes to SWL for calculi located within the kidney across all stone compositions, with very low morbidity [15]. Stone-free rates of approximately 80% can be expected for renal stones of 1 cm or smaller in size treated by URS [15]. In the patient with a high attenuation stone or a large skin–stone distance, URS is preferred to SWL as the difference in success rate is significant [15].

Finally, PCNL yields very high clearance rates for small renal calculi, but is a relatively morbid procedure for a stone of 1 cm or less, considering the success rates achieved with less invasive procedures [15]. In general, PCNL should not be considered as optimal initial management in renal stones of 1 cm or less, unless extraneous factors are at play.

For stones of 1 cm or less in the lower pole, the decision-making is slightly more complex. Assuming observation has failed or surgery is required for symptomatic stones, again the urologist is faced with a choice between SWL, URS, and PCNL. As with stones in the remainder of the kidney, a low attenuation stone and a favorable skin–stone distance would favor SWL, while the converse would favor URS. In this patient population there is just one small randomized trial to guide decision-making [23]. A total of 67 patients were randomized to either URS or SWL for 1-cm or smaller lower pole stones. Although stone-free rates were uniformly low (35% for SWL and 50% for URS), it should be noted that follow-up was performed with CT, which is extremely sensitive for detecting fragments [23]. There was no statistically significant difference between the two techniques, but URS did lead to a slightly higher stone-free rate and was associated with more complications [23]. Percutaneous management remains an excellent option for stone clearance, but, once again, the trade-off in morbidity and invasiveness for that optimal success rate must be considered. Unfavorable renal anatomy, such as a long infundibulum or acute angle of the lower pole calyx, or extremely dense/difficult to fragment stones may make PCNL the optimal initial choice.

Renal stones 1–2 cm in size

As renal stones increase in size, management changes slightly; PCNL assumes a more important role, as its superior ability to clear stones is a reasonable trade-off for the higher morbidity of the procedure. In addition, especially in the lower pole, SWL becomes a less effective modality. URS is useful for many of these stones, though its role is not as well tested as SWL or PCNL.

For renal stones, SWL remains a treatment option in this size range. A nomogram developed by Kanao *et al*. offers good estimates of stone clearance and can help guide decision-making [24]. For a renal pelvic stone, the chances of clearance at 3 months after a single SWL session are 43% for stones of 16–20 mm and 64% for stones of 11–15 mm in size [24]. For stones located in a calyx, the comparable stone-free rates are 35% and 57%, respectively [24].

As already stated, advances in equipment for stone management over recent years mean that virtually any location in the kidney can be readily accessed with flexible ureteroscopes. Concomitantly, there has been an effort to manage larger renal calculi with URS in order to assess its role compared with the more invasive PCNL (Figure 55.5). A small study of URS compared to PCNL for 1–2-cm renal stones showed a slightly lower stone-free rate of 67% versus 87%, but without any complications in the URS arm [25].

With this size of stone, especially in the lower pole, PCNL assumes the more dominant role in management. The morbidity of the procedure is often tolerable given the uniformly high clearance rates after PCNL compared with alternatives. In the Lower Pole I study, PCNL led to 93% stone-free rates in 1–2-cm lower pole renal stones, versus 23% for SWL [26]. In the URS versus PCNL trial mentioned above, there was a 20% higher rate of stone clearance with PCNL [25]. Auxiliary procedures were required in close to 40% of cases after SWL, as compared to a mere 6% with PCNL for 1–2-cm lower pole stones [26].

Renal stones greater than 2 cm in size

When approaching stones greater than 2 cm in size, the success rate of PCNL is unparalleled compared with the alternatives. Both SWL and URS have been utilized with stones of this size, but clearance often requires multiple procedures, whereas PCNL still has a high rate of success with one procedure.

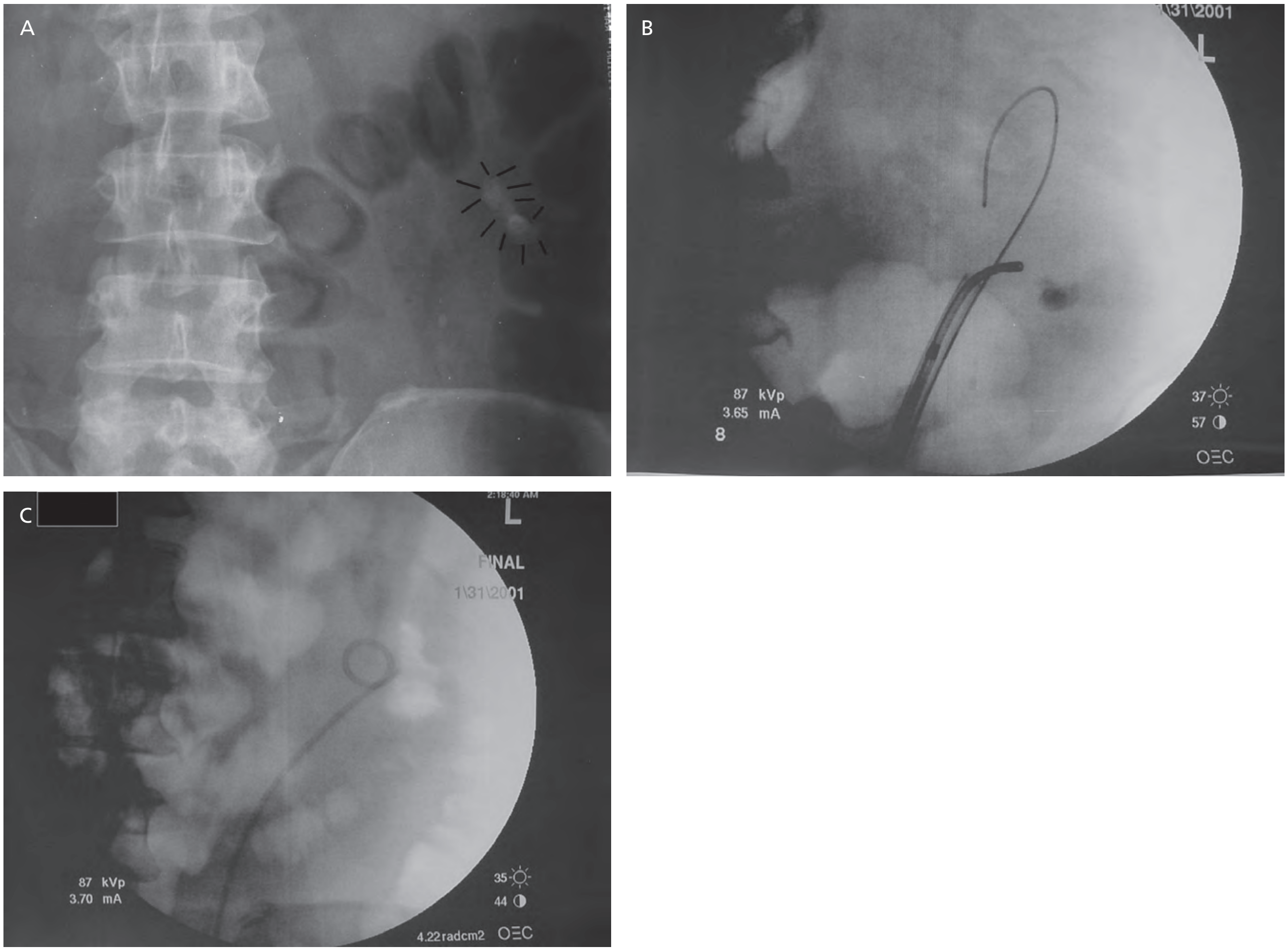
The nomogram by Kanao *et al*. suggests clearance for renal stones greater than 2 cm in size is 30% for renal pelvic stones and 23% for calyceal stones [24]. Likewise, for URS stone clearance is feasible for stones over 2 cm in size, but this requires an average of 2.3 URS procedures per patient [27]. In the Lower Pole I cohort, six of seven patients with stones greater than 2 cm in the lower pole were cleared with PCNL, whereas only one in seven patients were cleared with SWL (Figure 55.6) [26].

Clearly, for staghorn calculi and assuming that adequate renal function is present, PCNL is the mainstay of treatment, with procedures such as laparoscopic and open pyelolithotomy/nephrolithotomy being reserved for unique situations. (Figure 55.7) Stone-free rates approach nearly 80% with a single percutaneous procedure [28], and can reach up to 95% when flexible scopes and laser lithotripsy are included in the procedure [28].

In one study involving patients with renal large stones in whom PCNL was contraindicated or refused, a combination therapy using SWL + URS has been described [29]. The authors reported a low initial procedure success of 14%, but when combined with medical therapy or second-stage SWL and/or URS, a stone-free rate of nearly 77% was achieved [29].

Summary

For renal stones, several variables contribute to the decision as to which stone therapy is optimal for initial management. For asymptomatic stones of 1 cm or smaller in size, a trial of observation is certainly reasonable, though patients should be aware that stones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B
\31\2001
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87 kVp
3.65 mA
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57
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87 kVp
3.70 mA
35
44
4.22radcm2
OEC

Figure 55.5 (A) Fluoroscopy of left partial staghorn renal stone (demarcated by lines). (B) Fluoroscopy during ureterorenoscopy (URS) of left partial staghorn renal stone. Mid procedure, note clearance of stone is underway. (C) Fluoroscopy during conclusion of URS with stent in position and stone cleared from lower pole.

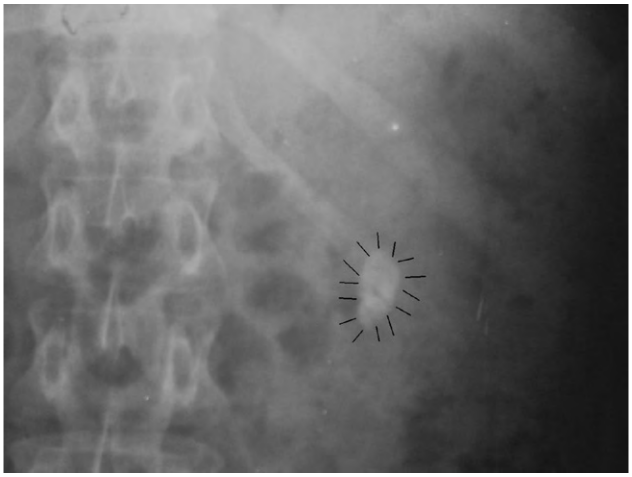

Figure 55.6 Fluoroscopy of large left lower pole stone (demarcated by lines).

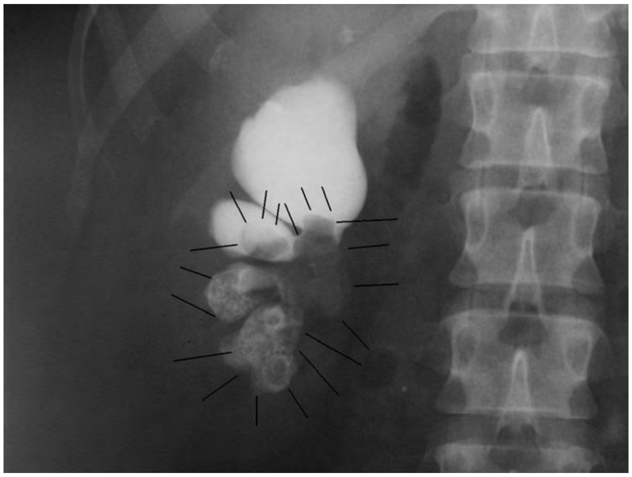

Figure 55.7 Fluoroscopy during intravenous urography showing large right staghorn renal calculi (demarcated by lines) manifesting as filling defect occupying lower and mid calyces, and renal pelvis.

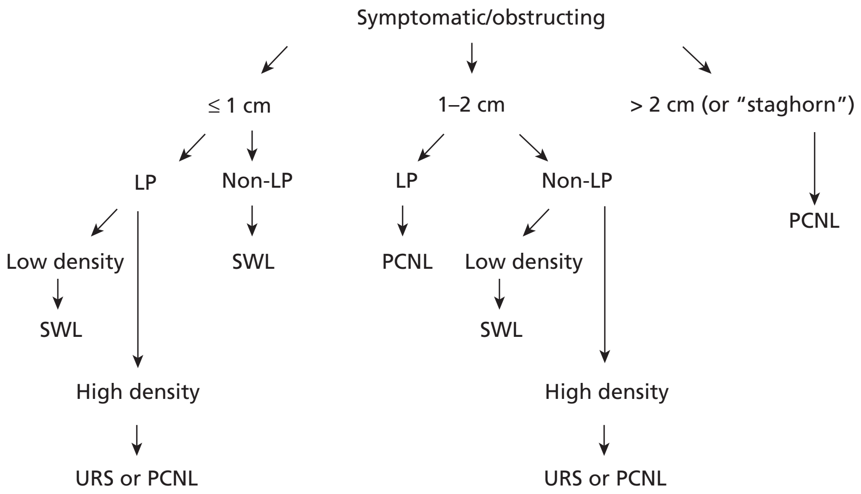

Figure 55.8 Renal calculi: optimal initial management strategy. SWL, shock-wave lithotripsy; URS, ureterorenoscopy; PCNL, percutaneous nephrolithotomy; LP, lower pole.

often require treatment or become symptomatic with the passage of time. For stones of 1 cm or smaller in size that warrant treatment, SWL and URS are associated with fair-to-moderate clearance rates and relatively low morbidity. As stones increase in size, especially with a lower pole location, PCNL becomes the most important means of treatment. As stones increase in size over 2 cm, PCNL is the preferred means of management (Figure 55.8).

Stones in calyceal diverticula

Stones presenting in a calyceal diverticulum are an infrequent occurrence, though often symptomatic. Treatment options available for these calculi include SWL, URS, PCNL, and laparoscopic approaches [30]. Since this condition is relatively rare, robust data comparing treatment modalities are lacking.

In a 15-year retrospective assessment comparing SWL and PCNL, PCNL had a much greater stone-free rate of 83%, while for SWL it was only 21% [31]. On the other hand, 61% of patients treated with SWL were rendered symptom free. Recurrence rates were roughly 10% in each group [31].

URS is also efficacious, especially when the diverticulum has a narrow and stenotic neck, hindering passage of fragments after SWL [32]. Using both the flexible ureteroscope and the holmium laser, many of these diverticula can be cleared of their stone burden, with smaller stones again being more amenable to successful clearance.

In the case of a posterior diverticulum, PCNL is an excellent means of accessing the diverticulum, as well as clearing its stone burden and possibly ablating the lining of the diverticulum [30, 32]. Finally, in the event of an anterior diverticulum, a laparoscopic approach has been successfully applied and thus offers an additional treatment option [30].

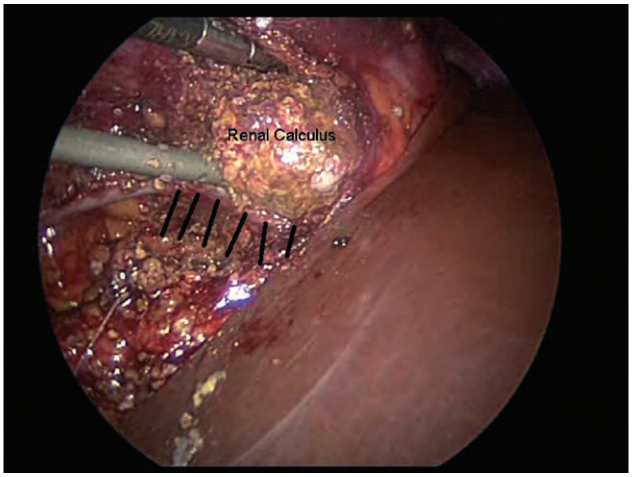

Figure 55.9 Intraoperative view during laparoscopic pyelolithotomy. The stone is visible as it is being extracted, while the lines demarcate the edge of the pyelotomy incision.

Laparoscopic and open stone surgery

The advent of SWL, better ureteroscopes, and PCNL has essentially rendered conventional stone surgery obsolete. Nonetheless, circumstances do arise, though rarely, where a laparoscopic or open approach is indicated [33]. For ureteral calculi, operative intervention is rarely needed; however, large impacted stones that fail SWL, URS, or antegrade removal would be candidates [33]. For such stones a laparoscopic approach can be utilized *in lieu* of an open ureterolithotomy [33].

For renal stones, an open or laparoscopic approach can be considered in select circumstances as well (Figure 55.9). In the event of failed PCNL, SWL, or URS, especially after multiple procedures, there is a role for formal operative intervention [33]. Additionally, in the event of a staghorn calculus where clearance seems unlikely in a reasonable number of minimally invasive procedures, open or laparoscopic surgery is an option [33]. Occasionally concomitant surgery on an unrelated organ system would be an indication to perform an open procedure on a large renal stone, as would concurrent surgery to repair a ureteral stricture [33]. Finally, some patients' body habitus precludes fluoroscopy, endoscopy, or positioning for SWL and thus leaves the surgeon with no choice but an open or laparoscopic approach to a urinary stone [33].

Conclusions

Modern stone management involves multiple treatment choices for the urologist. Salient features of contemporary management include the increasing role for MET in distal ureteral stones, the increasing role of URS for ureteral stones of all locations, especially those of higher density unlikely to respond to SWL, and the unparalleled role of PCNL for renal stones greater than 2 cm in size.

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CHAPTER 56

Management of Urolithiasis during Pregnancy

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Anatomic changes during pregnancy

Pregnancy induces a number of anatomic changes within the urinary tract. Renal size increases secondary to an increase in renal vascular volume and increase in the renal interstitial space. Hydronephrosis of varying severity is experienced by approximately 90% of pregnant women by the third trimester. The hydroureter extends to the sacral promontory and is typically absent more distally. The hydroureteronephrosis of pregnancy results primarily from compression of the gravid uterus [1]. Physiologic hydronephrosis can affect 90% of right kidneys and up to 67% of left kidneys [2]. The hydroureter is more prevalent and severe on the right side, secondary to uterine dextrorotation as well as a pressure-reducing effect of the sigmoid colon on the left side. The ureteric smooth muscle relaxation due to increased levels of progesterone has also been implicated in the development of gestational hydronephrosis [3, 4]. However, this mechanism may contribute to the early development of hydronephrosis, between 6 and 10 weeks of gestation, while the mechanical factor remains the major cause thereafter. Support for a primarily mechanical theory includes absence of urinary tract gestational ureteral dilation below the pelvic brim in patients with a pelvic kidney and in those who have undergone previous urinary diversion. The bladder is displaced anterosuperiorly by the gravid uterus, bladder capacity increases, and the detrusor muscle becomes relatively hypotonic and has decreased sensation (Table 56.1). The urothelium becomes congested and hyperemic.

Physiologic changes during pregnancy

Pregnancy induces physiologic changes in many organ systems, including the renal system (Table 56.2). Glomerular filtration rate (GFR) and renal plasma flow (RPF) increase by 40–65% and 50–85%, respectively [5] secondary to an increase in the cardiac output and decrease in the renal vascular resistance. Creatinine clearance increases by up to 50% [6], leading to lower serum creatinine and urea levels, a higher level of filtered glucose and glucosuria, and higher level of urine sodium, calcium, uric acid, citrate, magnesium, and glucosminoglycans. Enhanced renal filtration additionally affects dosing of antibiotics as well as anesthetic agents. Other nonrenal systems undergo physiologic changes as well.

Mineral metabolism and stone formation during pregnancy

The homeostasis of urolithiasis-promoting and -inhibiting factors is altered in pregnancy.

Placental 1,25-dihydroxycholecalciferol increases intestinal resorption of calcium as well uptake of calcium from bone. The increase in absorbed calcium is offset by an increase in GFR and subsequent increased filtered load of calcium. Parathyroid hormone (PTH) secretion is decreased, suppressing the tubular resorption of calcium. Thus, serum calcium levels generally remain unchanged and hypercalciuria occurs. Uric acid and oxalate excretion is increased due to increased GRF, and

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Table 56.1 Anatomic changes in the genitourinary tract during pregnancy.

System	Anatomic changes
Kidney	Renomegaly Hydronephrosis
Ureter	Hydroureter
Bladder	Anterosuperior displacement Increased capacity
Urethra	Urothelial hyperemia and congestion Squamous metaplasia

Table 56.2 Physiologic changes during pregnancy.

System	Physiologic changes
Genitourinary	
Kidney	↑ Blood flow and vascular volume ↑ GFR ↑ Proteinurea, uricosuria, calciuria, and citraturia ↓ Serum creatinine and blood urea nitrogen
Bladder	↓ Sensation and relative hypotonia
Cardiovascular	↑ Cardiac output ↑ Heart rate and stroke volume ↑ Blood volume ↓ Systemic vascular resistance ↓ Cardiac output near end of pregnancy ↓ Venous return ↓ Hematocrit
Respiratory	↑ Consumption of oxygen Hypoxemia Hypoventilation ↓ Functional residual capacity
Hematologic	Hypercoagulable state ↑ Factors VII, VIII, and X ↑ Fibrinogen ↓ Fibrinolytic activity
Gastrointestinal	↓ Gastrointestinal motility Relaxation of gastroesophageal sphincter

fetal and dietary factors [6–8]. Hypercalciuria, uricosuria, and oxaluria all create a favorable environment for renal calculus formation.

Pregnancy, however, is not associated with an increased incidence of urolithiasis compared to the nonpregnant population [9, 10]. This is most likely explained by the increase in filtered citrate, magnesium, and glycosaminoglycans [6–8], all of which are known inhibitors of crystal aggregation and growth.

Table 56.3 Differential diagnosis of acute abdominal pain in pregnancy.

Urologic causes	Gynecologic and obstetric causes	General surgical causes
Urolithiasis Pyelonephritis	Premature labor Placental abruption Chorioamnionitis Ectopic pregnancy Ovarian torsion Pelvic inflammatory disease	Appendicitis Cholecystitis Diverticulitis Intestinal obstruction Gastroenteritis Hernia Pancreatitis Mesenteric lymphadenitis

Renal calculi during pregnancy are documented to be composed primarily of calcium phosphate (74%) and calcium oxalate (26%) [11].

Incidence

The incidence of symptomatic urolithiasis in pregnancy is between 1 in 244 and 1 in 2000 pregnancies [12–14]. The overall incidence of urolithiasis is uncertain, but is estimated to be higher, as some asymptomatic renal calculi may remain undetected. There are no observed differences in the rate of urolithiasis between pregnant and nonpregnant women [15, 16].

The average age of presentation is 27 [17] with 80–90% of cases detected during the second and third trimester. Urolithiasis seems to be higher in multiparous women, in caucasian patients, and in patients with a history of hypertension and renal disease [17, 18]. Ureteral calculi present twice as often as renal calculi [19, 20]. Up to 30% of patients have a history of stone disease [21].

Presentation

Symptomatic pregnant patients may present with abdominal or flank pain (85–100%), gross (15–30%) or microscopic hematuria (95–100%), lower urinary tract symptoms, urinary tract infection, pre-eclampsia, and premature labor [22–24]. Nausea and vomiting are invariably present as well. A comprehensive differential diagnosis of abdominal pain during pregnancy is given in Table 56.3.

Acute abdominal or flank pain in pregnancy presents a unique diagnostic challenge. The clinician has to consider anatomic alterations induced by pregnancy that can lead to various conditions mimicking each other. For example, the appendix can be displaced superiorly after the first trimester and appendicitis may mimic pyelonephritis or cholecystitis [25].

Table 56.4 Fetal radiation doses for radiologic tests.

Procedure	Fetal dose (mGy)
CT scan (conventional)	8.0–49
CT scan (limited)	0.244–1.372
IVU	1.7–10
KUB	1.4–4.2
Nuclear renogram (MAG3 or DTPA)	0.2–4.0
MRI	No radiation, no known adverse effects
Ultrasonography	No radiation, no known adverse effects

CT, computed tomography; IVU, intravenous urography; KUB, kidneys, ureters, bladder plain film; MAG3, mercaptoacethyltriglycine; DTPA, diethyltriamine pentaacetic acid; MRI, magnetic resonance imaging.

Diagnostic tests

Imaging and radiation exposure

Accurate diagnosis of abdominal pain in pregnancy largely depends on diagnostic imaging. The necessity of diagnostic imaging and exposure to ionizing radiation is commonly anxiety provoking for both patients and clinicians. Use of the ionizing radiation needs to be avoided whenever possible, due to its potential teratogenic effects. When its use is unavoidable, a detailed discussion with patients is required, carefully explaining the potential risks associated with its use. Application of radiation dose reduction techniques is mandatory. The delivered dose of radiation should be as low as possible, while maintaining the quality of diagnostic image that is useful for diagnosis. Effects of ionizing radiation on the fetus can be categorized into four classes: intrauterine fetal death, fetal malformation, disturbance of growth and development, and mutagenic–carcinogenic effect [26, 27]. The risk of exposure is also dependent on the dose of the radiation and fetal gestational age [28].

The radiation dose is measured in Gray units (Gy, SI system), representing the amount of ionizing radiation absorbed by tissue. Previously, the radiation dose was measured in rads (1 Gy equating to 100 rads), representing the radiation dose delivered and not necessarily absorbed by the tissues. The delivered fetal dose for each diagnostic imaging procedure varies according to the technique used (Table 56.4) and maternal body configuration. Most diagnostic procedures deliver fetal doses below 50 mGy [29]. This dose of radiation has not been associated with an increase in fetal anomalies or pregnancy loss [30]. The American College of Obstetricians and Gynecologists recommends that "Women should be counseled that the X-ray exposure from a single diagnostic procedure does not result in harmful effects" [30].

Table 56.5 Effects of significant radiation exposure on the fetus.

Gestational age (weeks)	Radiation effect
2–4	All lethal or no impact on fetus, without any malformations present
4–10 (organogenesis)	Microcephaly, growth retardation, gross malformations
10–17 (peak neurologic development)	Microcephaly, mental retardation, growth retardation and sterility in adult life
17–40	Adverse effects seen rarely, if ever

The effects of radiation depend on the fetal gestational age [28]. Fetal tissues are most susceptible to ionizing radiation during the first trimester when organogenesis is occurring. Use of ionizing radiation should be avoided during this period. The teratogenic effects of radiation are summarized in Table 56.5. In addition, ionizing radiation has a potential to induce development of childhood cancers such as leukemia. Historic studies raised concern that *in utero* radiation exposure may increase the incidence of childhood malignancy by 1.3–2 times [28, 31]. However, more recent investigations have reputed this evidence [32]. The National Radiological Radiation Board concluded that the majority of diagnostic radiologic procedures performed in an individual pregnancy presents no substantial risk and carries a less than 1 in 5000 chance of developing a fatal childhood cancer (1 in 33 000 per mGy). Additionally, the risk is less than 1 in 10 000 for development of induced inheritable disease (1 in 40 000 per mGy) [33, 34].

Ultrasound

Ultrasonography (Figure 56.1) is the most useful initial test when acute abdominal or flank pain in pregnancy is investigated. The appeal of ultrasound derives from the lack of ionizing radiation and absence of harmful effects, documented over many years of use. Ultrasonography can effectively evaluate the renal parenchyma, pelvicalyceal system, dilated ureter, and to some extent visualize renal and ureteral calculi.

The accuracy of ultrasonography in the detection of renal calculi is reported to be between 34% and 86% [17–19]. This wide variation in the reported accuracy most likely derives from the fact that ultrasound is operator dependent. Additionally, ultrasonography is very nonspecific and often cannot distinguish between

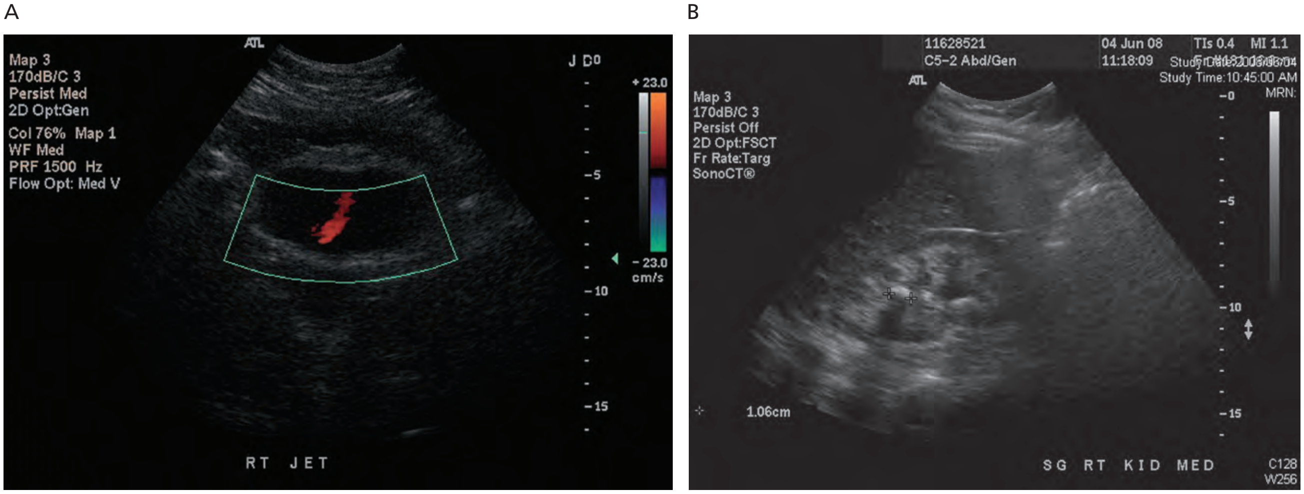
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Figure 56.1 Ultrasound images. (A) Bladder (Doppler) demonstrating an absence of left ureteric jet, in a 30-year-old pregnant woman, G1P1 GA 30 weeks. (B) Kidney with a right renal stone in a 31-year-old pregnant woman, G2P2 GA 28 weeks.

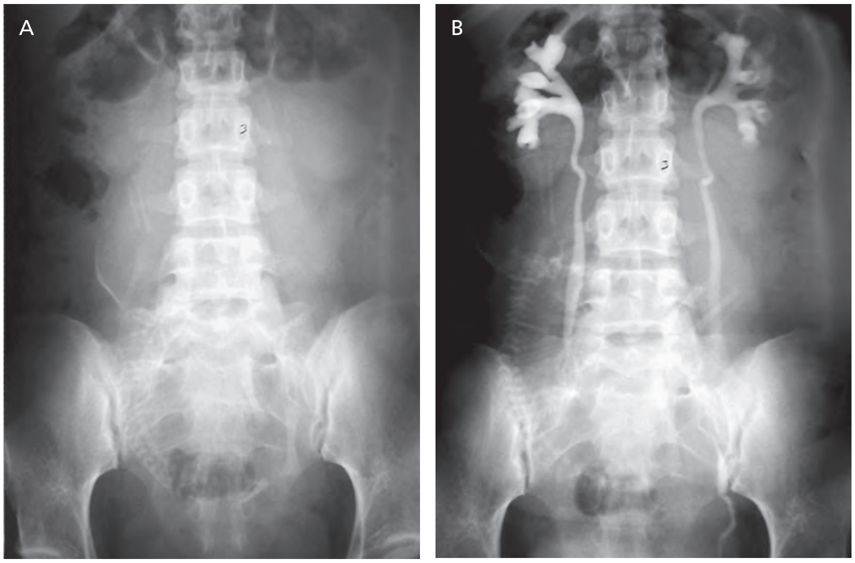

Figure 56.2 (A, B) Kidneys, ureters, and bladder intravenous urogram demonstrating a right ureteral calculus in a 30-year-old pregnant woman, G1P0 GA 29 weeks.

hydronephrosis of pregnancy and that secondary to calculi.

Several modifications to ultrasonography have attempted to improve its accuracy. Transvaginal ultrasound was demonstrated to be effective in the detection of distal ureteral calculi [35]. Detection of hydroureter below the pelvic brim, with any ultrasound approach, may alert the operator to the presence of distal ureteral calculi [36]. The presence of ureteral jets on ultrasound or Doppler ultrasound can exclude complete ureteral obstruction in 80–100% of cases [37].

Resistive index (RI) measurements may increase the accuracy of ultrasonogarphy in distinguishing between the physiologic dilation and calculi-related obstruction [38]. An RI of 0.70 was demonstrated to have 87% accuracy, 45% sensitivity, and 91% specificity for diagnosis [38, 39]. Additionally, a difference in RIs (ΔRI) between the affected side and the normal contralateral kidney of 0.06 increases the sensitivity of ultrasonography to 95%, with specificity of 100% and accuracy of 100% [39]. This type of ultrasonography adjunct was demonstrated to be limited by pre-existing renal disease, nonsteroidal anti-inflammatory drugs (NSAIDs) and acute onset of obstruction (<6 h).

Intravenous urography

Intravenous urography (IVU) (Figure 56.2) is effective in describing anatomy and function of the collecting system, along with the site and degree of potential obstruction. IVU can be considered as a second-line investigation for hydronephrosis of pregnancy. Small published series report relatively high specificity in diagnosing renal calculi in pregnancy [17, 40]. If needed, a limited three-shot protocol should be used: a scout film, 15–20-min film, and a selected delayed image at 2h. Fetal shielding should be used at all times [41].

IVU, if considered, should be used judiciously due to potential risks of intravenous contrast and fetal radiation exposure. Intravenous contrast was demonstrated to cross the placenta in small quantities, but without any described teratogenic effects [42]. However, exposure to iodinated intravenous contrast during late pregnancy can lead to fetal thyroid suppression, and requires screening for neonatal hypothyroidism [42].

A limited IVU delivers 0.5mGy of radiation to the fetus, which is below the 5mGy safety point. Fetal shielding and films obtained in a prone position can further reduce the dose.

Computed tomography

A traditional computed tomography (CT) scan (Figure 56.3) remains contraindicated in pregnancy due to the high dose of ionizing radiation delivered. Recently, however, a low-dose CT scan protocol has been described for the detection of renal calculi during pregnancy. A low-dose CT scan protocol uses a pitch of 1.5 (from 0.75 in regular CT), 120kV, and a mean of 109mAs. With these modifications the mean delivered fetal radiation exposure is 705.5mrad (range 244–1372), although this is probably an overestimate due to maternal changes in body geometry. Obese patients receive a higher estimated dose on average. The resulting CT images are of much lower quality in comparison to traditional scans, but this investigation still provides high sensitivity and specificity for detection of renal and ureteral calculi.

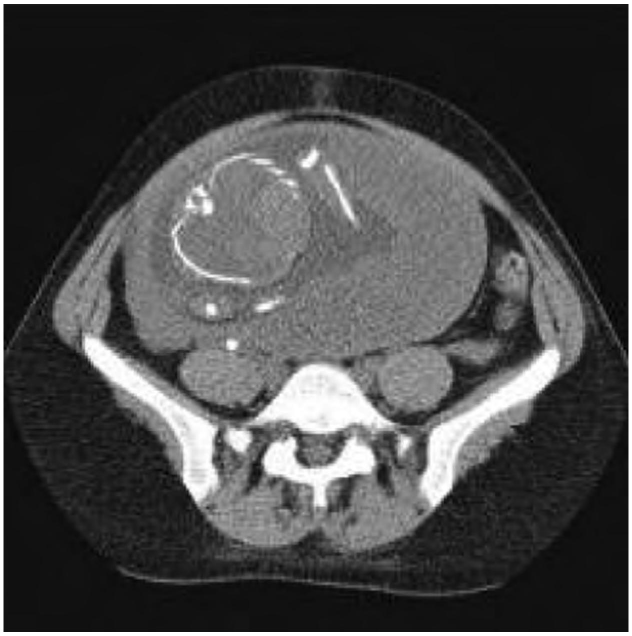

Figure 56.3 Low-dose CT scan demonstrating a right ureteral calculus in a 29-year-old woman, G1P0 GA 27 weeks (reproduced by permission of Mary Ann Liebert).

Based on the finding of a small Research Ethics Board (REB)-approved study, the authors concluded that a low-dose CT scan is more sensitive than ultrasound and improves decision-making. The judicious use of low-dose CT scans in pregnant women with flank pain and negative initial ultrasound is advocated [43].

Magnetic resonance

Magnetic resonance imaging (MRI) (Figure 56.4) in pregnancy produces high-quality images of urinary tract anatomy. Heavily weighted T2 MRI pulse sequences or use of intravenous gadolinium can produce precise urograms, comparable to those produced by IVU. The accuracy of MRI in delineating pathologic obstruction from hydronephrosis of pregnancy ranges from 93% to 100% [44]. MRI's diagnostic accuracy can be enhanced by combining it with Doppler ultrasonography and nuclear renography [45]. To date, no harmful effects have been reported with the use of MRI in pregnancy [46]. Experience with gadolinium is limited, but to date no adverse effects on a fetus have been reported. The National Radiological Radiation Board recommends avoiding gadolinium in the first trimester of pregnancy. The main limitation of MRI remains the inability to visualize the stone. The presence of the stone has to be inferred from several soft signs such as "signal voids," "double kink," and perinephric and periureteral edema. Additional limitations include the time-consuming nature of performing MRI (although this continues to improve with new generation scans), its lower availability, and high costs. Patients afflicted with claustrophobia also will not be able to undergo this diagnostic procedure.

Management

When to intervene?

The rate of spontaneous stone passage in pregnancy is between 64% and 84% [17, 21]. Up to 50% of the remaining stones will pass in the postpartum period [17]. Based on these data, the guiding principle of therapy remains that of conservative management. Conservative management requires hydration, antibiotics, antiemetics, analgesics, and close daily follow-up during the symptomatic period. Straining of urine is also advised. Medical expulsive therapy cannot be recommended as

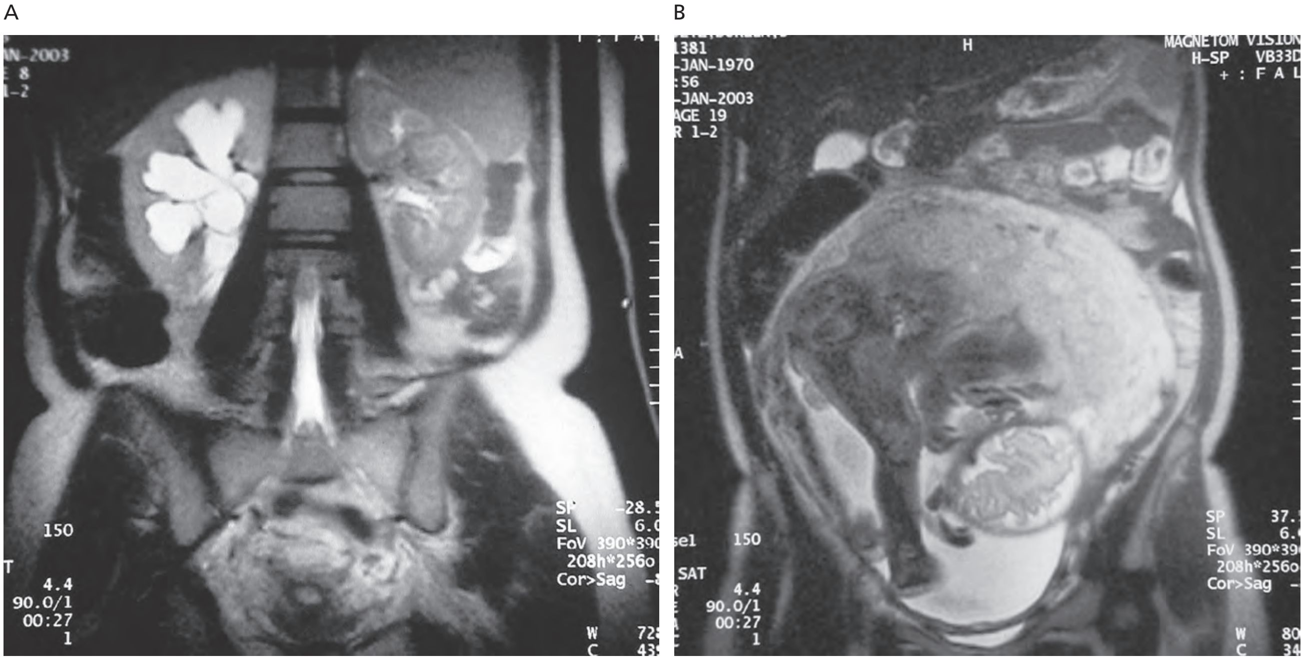

Figure 56.4 (A, B) MR images from a 25-year-old pregnant woman, G1P0 GA 26 weeks, suggestive of right renal calculus based on secondary signs.

part of conservative management, as alpha-blockers, calcium channel blockers, and corticosteroids are contraindicated in pregnancy [47].

Conservative management of urolithiasis will fail in approximately 15–30% of pregnant women [48]. Indications for intervention in symptomatic pregnant patients are the same as in the nonpregnant population. These include sepsis, renal failure from obstruction of a solitary kidney or bilateral obstruction, uncontrolled pain, premature onset of labor, pre-eclampsia, and poor access to expert urologic care.

Anesthetic risks

Use of anesthesia for nonobstetric surgery during pregnancy has a potential for inducing fetal congenital malformations, spontaneous abortion, and premature labor [49]. Thus, nonemergency surgery during pregnancy should not be performed. Open surgery should be considered only as treatment for septic patients who have failed to respond to any other therapeutic options and when endourologic expertise or equipment is not available [48, 50]. Performing any surgery during the first trimester was found to increase risk of miscarriage [51] and in the third trimester of premature labor [52]. The optimal time for performing nonobstetric surgical intervention during pregnancy is the second trimester [52].

In general, the dosing of both general and locoregional anesthetics during pregnancy is decreased [53, 54]. The increased levels of progesterone and endorphins that have been documented in pregnancy probably play a role in decreasing the minimal alveolar concentrations of the inhalational agents halothane and isofulrane [53], whereas progesterone has also been reported to enhance neuronal membrane sensitivity to local anesthetics [54], thereby diminishing the dose. Drug dosing for spinal and epidural anesthesia was reported to diminish even further in the later stages of pregnancy due to compression of the cerebrospinal space and subsequent epidural venous congestion [55].

Any surgical intervention during pregnancy should involve the obstetric team, for monitoring of the fetal heart rate and uterine activity. Fetal monitoring should continue for 24 h post intervention [56]. NSAIDs should not be used for analgesia as they may induce premature closure of the fetal ductus arteriosus [57].

Endourologic interventions

Ureteric stenting

Ureteral stenting represents a temporizing measure, with definitive management deferred until the postpartum period. This approach minimizes or eliminates the requirement for anesthesia, but has several drawbacks. Stent insertion can be accomplished using either fluoroscopy or ultrasound. Fluoroscopy is preferable, but is associated with exposure to ionizing radiation. If using fluoroscopy, fetal shielding and pulsed imaging can reduce radiation exposure. Ultrasound-guided insertion of a ureteric stent eliminates radiation exposure completely [58].

The main drawbacks of ureteric stenting during pregnancy are stent discomfort and stent encrustation. Stent discomfort is similar to that in the nonpregnant population and can manifest as an increase in urinary frequency and urgency, dysuria, mild gross hematuria, and flank pain. Stent discomfort in pregnancy is usually heightened secondary to presence of overactive bladder symptoms that many women experience in the later stages of pregnancy. The risk of stent encrustation during pregnancy is increased secondary to hypercalciuria and hyperuricosuria of pregnancy. This increased risk necessitates frequent stent exchanges, every 4–6 weeks [18, 59]. The cumulative risks of frequent stent exchanges may exceed that of a single definitive procedure.

Indications for a percutaneous nephrostomy

A percutaneous nephrostomy (PCN) tube is also a temporizing measure that provides immediate and efficient decompression of the urinary tract. PCN insertion can be achieved with ultrasound guidance and under local anesthesia (usually inserted by an interventional radiologist). The main advantages of this treatment modality are absence of ionizing radiation, minimal anesthesia requirements, avoidance of ureteral manipulation, and very effective drainage of the urinary tract. It also establishes a percutaneous tract for later definitive management of calculi. These attributes often make PCN insertion a preferred option for treatment of septic patients or patients during the first trimester [18, 50].

The main disadvantages of PCN tubes are the risk of bleeding during insertion, bacterial colonization, tube dislodgement, blockage by debris, and tube discomfort. PCN tube blockage, encrustation, and dislodgement necessitate PCN exchanges every 6–8 weeks as a preventative measure.

Ureteroscopy

At present, ureteroscopy is considered the procedure of choice in the management of symptomatic urolithiasis in pregnancy, following the failure of conservative management. Safe and successful ureteroscopic management requires modern endoscopic equipment and sufficient endourologic expertise.

The safety and effectiveness of ureteroscopy in pregnancy has been demonstrated in a number of small series [60–73] (Table 56.6). A recent meta-analysis of published reports has documented the safety of ureteroscopic stone extraction or intracorporeal lithotripsy in pregnant women to be equal to that in the nonpregnant population, and complication rates have been low (0–20%) [74].

Ureteroscopy can be performed under general or spinal anesthesia. Intravenous sedation with fentanyl and propofol has also been described. The patient is positioned in the modified dorsal lithotomy position

Table 56.6 Summary of studies of ureteroscopic management of urolithiasis during pregnancy.

First Author	Number of patients	Lithotripter used	Number stone-free (%)	Fetal or Maternal Complications	Level of Evidence
Rana *et al*. [76]	19	Pneumatic	15/19 (79)	None	3
Travassos *et al*. [66]	9	Basket	9/9 (100)	None	3
Geavlete *et al*. [67]	15	Laser Basket/grasper	14/15 (93)	None	3
Akpinar *et al*. [65]		Holmium : YAG laser	6/7 (86)	None	3
Usai *et al*. [68]	7 3	Pneumatic Basket/grasper	3/3 (100)	None	3
Ulvik *et al*. [69]	27	Basket/grasper	23/27 (71)	Ureteral perforation (1) Preterm delivery (1) Premature uterine contractions (2) None	3
Watterson *et al*. [61]	8	Holmium : YAG laser	7/9 (89%)	None	3
Lifshitz *et al*. [70]	4	Basket/grasper	4/4 (100%)	None	3
Lemos *et al*. [64]	14	Ultrasound Basket/grasper	13/14 (93%)	None	3
Sharifi *et al*. [71]	4	Pneumatic/basket	4/4 (100%)	None	3
Banon *et al*. [72]	8	Basket/grasper	8/8 (100%)	Fever (2)	3
Tekerlekis *et al*. [73]	16	Basket/grasper	12/16 (75%)	Premature uterine contractions (1)	3
Shokeir *et al*. [63]	8	Ultrasound Basket/grasper	5/8 (63%)	Maternal UTI (2)	3

[61–63]. Both rigid and flexible ureteroscopes can be used, with instruments sized 8F or smaller, which do not require the dilation of the ureteric orifice [64–66]. Ureteroscopy can be performed either with ultrasound guidance or with pulsed fluoroscopic imaging and mandatory fetal shielding. Performing ureteroscopy in pregnancy is not considered technically difficult, as physiologic dilation of the ureter helps with the manipulation of flexible ureteroscopes [67].

The holmium : YAG laser has emerged as the preferred and safest intracorporeal lithotripter utilized in pregnancy [68, 69]. The holmium : YAG laser has a wide safety margin due to its unique wavelength (2100 nm) and limited depth of penetration in a fluid environment (< 0.5 mm from the tip of the probe). Use of the holmium : YAG laser was reported to result in an 89% overall stone-free rate [68]. A theoretical concern with its use is the production of cyanide during laser lithotripsy of uric acid stones. However, there are no published reports of cyanide toxicity to date [74, 75]. The risk of cyanide toxicity should be negligible, as any cyanide produced during the lithotripsy should be diluted out from the urinary tract with the irrigant.

Alternative intracorporeal lithotripters used in pregnancy include the ballistic or pneumatic lithotripter, ultrasonic lithotripter, and forceps crushers [76–78].

Ultrasonic lithotripsy is known to be very safe to the surrounding tissues [79], but there is a theoretical concern regarding fetal auditory development. However, there is evidence to suggest that the peak pressure of the sound emitted by all intracorporeal lithotripters within the ureter does not affect fetal auditory development [80]. The main limitation of ultrasonic lithotripsy remains the rigid nature of the probe that restricts its use to rigid or semi-rigid ureteroscopes.

The electrohydraulic lithotripter (EHL) has the lowest margin of safety for use in pregnancy. EHL generates high peak pressures and the electrical energy generated from the probe poses a potential risk for fetal injury and induction of premature labor. It is not recommended for use in pregnancy [81, 82].

The potential risks of ureteroscopy are similar to those in the nonpregnant population and include urinary tract infection, sepsis, ureteral perforation, and ureteral avulsion. In experienced hands and with use of proper equipment the complication rates are very low (Table 56.5).

Percutaneous nephrolithotomy

Percutaneous nephrolithotomy (PCNL) is not advised during pregnancy. The necessity of prolonged general anesthetic, prone positioning, and need for fluoroscopy make PCNL a high-risk procedure during pregnancy. PCNL should be deferred until after delivery.

Extracorporeal shock-wave lithotripsy

Extracorporeal shock wave lithotripsy (SWL) is presently contraindicated in pregnancy due to the potential adverse effects of high-energy shock waves on the fetus and the ionizing radiation exposure. However, treatment of six unknowingly pregnant women was not found to result in fetal malformations or chromosomal anomalies in the children [83].

Conclusions

The safe and effective management of calculi in pregnancy requires a thorough knowledge of anatomic and physiologic changes that occur with each stage of pregnancy. Both fetal and maternal health must be considered. The use of ionizing radiation has to be minimized. Clinicians must use a team approach and adhere to strict indications for intervention in order to maximize a successful outcome for the mother and fetus.

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CHAPTER 57

Management of Stones in Obesity

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Introduction

Recent data from epidemiologic studies suggest that the prevalence of overweight and obese individuals has significantly increased from 15% to 30% over the past 20 years [1]. Obesity is a major public healthcare problem. The body mass index (BMI) is an objective measure of obesity and patients with a BMI greater than 40 kg/m^2 have an extremely high relative risk of comorbid diseases: hypertension, diabetes mellitus, hyperlipidemia, hypercholesterolemia, and cardiovascular disease [2]. Additionally, large population-based studies have shown that obesity and weight gain increase risk of kidney stone formation due to alterations in urinary metabolite excretion in adults [3, 4]. In an interview-based study of patients with urolithiais, the prevalence of obesity was 17.2–19.3% [5]. The management of obese stone formers is now safer and more successful thanks to advances in minimally invasive techniques and improvements in anesthesia, but these patients still present some specific technical challenges which the urologist needs to be aware of to provide optimum care.

Obesity and stone risk

Studies have shown that the most common stone component in obese patients is calcium oxalate and they have a slightly higher incidence of uric acid stones as well [4, 6]. In addition, these studies suggest that obesity is strongly associated with an increased risk of stone episodes. Several factors have emerged as causes of stone formation in obesity.

Urine pH

Urinary pH is an important factor in stone formation. Li *et al*. demonstrated that urine pH is inversely related to BMI among obese patients with urolithiasis: mean urine pH in normal body weight, overweight, and obese patients was 6.25, 6.14, and 6.00, respectively [7]. Hyperinsulinemia, insulin resistance, and gout diathesis may be factors that lower urinary pH in obesity.

Hyperinsulinemia

Obese patients have a higher incidence of diabetes mellitus, which correlates with hyperinsulinemia or insulin resistance. Insulin is known to stimulate the synthesis of ammonia and sodium–hydrogen exchange in the renal tubule, which mediates ammonium excretion in urine. Hyperinsulinemia-associated obesity contributes to the development of calcium stones by decreasing urinary citrate and increasing urinary excretion of calcium, uric acid, and oxalate [8]. Insulin resistance may result in defective ammonium production and the ability to excrete acid, thus lowering urine pH.

Metabolites

High metabolic load is another important factor for urolithiasis in obesity. Powell *et al*. demonstrated that increased urinary concentrations of sodium, oxalate, uric acid, phosphate, and cystine were found in obese

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patients compared with nonobese counterparts, and these urinary changes were mostly seen in obese women [4]. Taylor and Curhan reported that obese male patients excreted more urinary oxalate, calcium, uric acid, sodium, and phosphate than nonobese patients, as did obese women patients, although increased urinary calcium was seen only in younger women. An inverse relationship between BMI and urine pH was seen also in both men and women [9].

Inhibitors

Urinary citrate excretion is determined by acid–base status and therefore the intracellular pH of renal proximal tubule cells [10]. Acid load promotes proximal tubular reabsorption of citrate and reduces citrate synthesis. Thus, the lower urinary pH commonly seen in obese patients leads to hypocitraturia. Magnesium complexes with oxalate, thereby potentially reducing oxalate absorption in the gastrointestinal tract. Consequently, high metabolic load and decreased excretion of inhibitors such as citrate and magnesium facilitate urolithiasis in spite of increased urinary volume [11].

Diet and medical therapy

Regarding the negative effects of comorbid disease and urolithiasis on kidney function, together with the limitations of stone surgery, medical management of stone disease is the most important goal for preventing further recurrences in morbidly obese patients.

Dietary modifications and weight loss

Dietary modifications can reduce urinary excretion of stone constituents or increase urinary inhibitors. Dietary changes alone may be sufficient to prevent stone recurrence without the need for drug therapy in low-risk stone formers; also, dietary modifications should always accompany drug therapy in patients at high risk of recurrence. Weight loss and dietary modifications, such as increasing fluid and fiber intake, restricting intake of red meat, salt, and oxalate, and only moderate calcium intake, may alleviate urinary electrolyte changes in some patients [12]. Ekuro *et al*. found that appropriate dietary modification and tailored medical treatment successfully lowered the recurrence rate of stone disease in obese patients [13]. In general, patients are recommended to consume enough fluid to maintain a urine output of at least 2 L/day.

Potassium citrate and urine pH modifications

Potassium citrate acts by providing an alkali load and probably reducing urinary calcium. It increases urinary pH and citrate, thereby increasing urinary inhibitory activity. Potassium citrate can be used in hypocitraturic patients and normocalciuric calcium stone formers, regardless of other associated abnormalities. In a randomized trial, potassium citrate was shown to reduce stone recurrence rates by 75% among hypocitraturic stone formers [14]. In patients with gouty diathesis, potassium citrate raises urinary pH and reduces uric acid-induced calcium oxalate stone formation. It has been shown to be effective in reducing stone recurrence rates for patients with hyperuricosuric calcium oxalate nephrolithiasis and lack of tolerability for allopurinol [15]. Increasing the urine pH to above 5.5 and preferably between 6.5 and 7.0 plays a key role in the management of gouty diathesis [16]. Potassium citrate should be given at a dose sufficient to maintain the urine pH at approximately 6.5. Alkalinization of the urine to a pH higher than 7.0 should be avoided as this will increase the risk of calcium phosphate stone formation.

Potassium citrate is prescribed at a starting dose of 10 mEq three times daily, or 20 mEq twice daily. It is prescribed along with a thiazide diuretic or indapamide to reduce the risk of thiazide-induced hypokalemia and hypocitraturia in patients with hypercalciuria. For patients with enteric hyperoxaluria, potassium citrate therapy can raise urine pH and citrate, and for these patients can be given in dosages higher than those used for idiopathic calcium nephrolithiasis (up to 120 mEq/day).

Allopurinol

Two pharmacologic approaches to the management of hyperuricosuric calcium oxalate nephrolithiasis are decreasing the production of uric acid and altering the urinary milieu for uric acid in a dissolved state. Allopurinol (300 mg/day) may be given to patients who are unable or unwilling to comply with dietary protein restriction. Diluting urine to maintain uric acid at a low concentration and the use of an alkalinizing agent such as potassium citrate (30–60 mEq/day) may promote dissolution of uric acid.

Interventional therapies

The American Urological Association (AUA) clinical guidelines for urolithiasis indicate that spontaneous stone passage is seen in between 10% and 53% of patients with stones of 6–10 mm [17], indicating that patients with a stone size larger than 5 mm may encounter some stone-related complications, such as renal colic, urinary obstruction, and infection, and may require interventional therapies. However, obesity poses a number of problems in the management of stone disease from diagnosis and imaging through to anesthesia and surgery. Beyond these pitfalls, treatment success of interventional therapy is negatively influenced by obesity as well, although some technical modifications have been reported to increase the success rates. Below, the basic features of these therapies in obese patients are emphasized.

Extracorporeal shock-wave lithotripsy

Extracorporeal shock-wave lithotripsy (ESWL) has been widely used as the primary treatment modality for most renal and ureteral calculi [12, 18]. Uncorrected coagulopathy, pregnancy, severe skeletal deformity, and morbid obesity were accepted contraindications of this modality. Advantages of ESWL for renal and ureteral stones are avoidance of anesthesia-related complications and the ability to perform it many times without increasing morbidity. However, optimal ESWL treatment in obese patients is restricted by the table's weight limit (135 kg for the Dornier HM3) and the short focal length (12–14 cm) of lithotripters [19]. Treatment success for renal stones of 20 mm or smaller was reported to be above 90%, and 92.6–97.5% for ureteral stones of 10 mm or smaller in the overall patient population [12]. However, Delakas *et al*. suggested that the probability of ESWL failure was increased 1.9 fold in patients with a BMI over 30 kg/m^2 [20]. Munoz *et al*. reported that the success rate of ESWL for renal and ureteral stones was 72% in obese patients [21]. Additionally, Ackerman *et al*. stated that BMI was an independent predictive factor of ESWL failure and patients with a BMI of 28 kg/m^2 or less had better treatment results [22]. Recent studies emphasize the importance of skin–stone distance in stone clearance, measured as the mean value of three distances from the renal stone to the skin at 0°, 45°, and 90° and using a radiographic caliper or computational measuring device [23, 24]. They suggested that a skin–stone distance greater than 10 cm more strongly predicted ESWL failure than BMI or Hounsfield units [25]. The success rates of ESWL for lower calyceal stones are low in obese patients compared to their nonobese counterparts.

Reducing the focal length by using an abdominal strap and selecting lithotripters with long focal length and high energy settings may improve the success rate of ESWL [26]. Additionally, Mezentsev reported that ESWL with "blast path" technique in morbidly obese patients gives better treatment results (87%) even if the stone is located a few centimeters from the center of the focal area [27]. Tips and tricks for ESWL in obese patients are listed in Table 57.1.

Table 57.1 Tips and tricks for shock-wave lithotripsy in obese patients.

Use abdominal strap to reduce the focal length
Choose a long focal length lithotripter or high energy setting
Use "blast path" technique when the stone is located a few centimeters from the center of focal area

Ureterorenoscopy

Owing to recent technologic advances, retrograde endoscopic lithotripsy for renal and ureteral stones with flexible and semi-rigid ureterorenoscopy (URS) has become a feasible treatment option. According to the European Association of Urology (EAU)/AUA Guideline Panel on ureteral stones, URS gives a superior stone-free rate in proximal ureteral stones larger than 1 cm, and in all mid-ureteral and distal stones when compared with ESWL [18]. Additionally, URS can be safely performed in special circumstances, such as pregnancy, children, ectopic, pelvic or transplant kidneys, and patients on anticoagulation medication. Although ESWL is the accepted first-line treatment modality for renal stones (<2 cm), it may be precluded by the weight limitations of the treatment table and difficulties in focusing on the stone due to impaired radiologic imaging (fluoroscopy or ultrasound) and short focal length [28]. Flexible URS is indicated in renal stones of less than 15 mm that do not respond to ESWL [29]. Dash *et al*., in a stone-matched comparison (obese vs nonobese), reported that URS treatment for renal calculi was effective in obese patients as well as nonobese counterparts without increasing morbidity [30]. In a recent study in 107 patients, Natalin *et al*. evaluated their URS treatment outcomes for renal and ureteral stones according to BMI, and stone size and location. Overall stone-free rates were 91%, 97%, and 94% in normal weight, overweight, and morbidly obese patients, respectively. They found no significant difference in terms of stone location (renal/proximal, mid-, and distal ureteral stones) and size (cut-off dimension was 1 cm) in all groups. Consequently, they emphasized that URS treatment is an acceptable modality for all ureteral calculi with a high success rate in obesity, and it may be preferable to ESWL for obese patients [31].

Generally, additional technical modifications are not recommended when performing URS in obese patients. To prevent further interventions, recent developments in URS treatment, such as digital flexible URS, ureteral access sheaths, holmium laser lithotripsy, and nitinol stone baskets, may be used [32]. Flexible URS may guide percutaneous renal access in obese patients or when a previous attempt has failed. Khan *et al*. described a technique in which a flexible URS was advanced to the intended calyx with the patients in a prone split-leg position, and percutaneous calyceal puncture was performed under direct vision [33].

Percutaneous nephrolithotomy

Percutaneous nephrolithotomy (PCNL) is recommended for kidney stones larger than 2 cm and for staghorn calculi [34]. PCNL is also indicated in cases of SWL failure, stones with concurrent ureteropelvic junction obstruction, stones within calyceal diverticuli, and anatomic abnormalities (e.g. horseshoe kidney). The absolute contraindications are active urinary tract infection and uncontrolled coagulopathy. Studies suggest that the success and complication rates of PCNL in obese patients are comparable with those for the normal weight population [35–37]. Pearle *et al*. found that the stone-free rates for staghorn and nonstaghorn stones in obese patients were 84.2% and 90.2%, respectively [35]. Of these patients, 14% had minor or major complications and 8.8% needed blood transfusion, and their mean hospital stay was 4.9 days. The authors also reported that technical modifications and appropriate instrumentation were necessary to improve the stone-free rate in this group of patients. Similarly, El-Assmy *et al*. reported their 4-year experiences of PCNL in 1121 patients. The stone-free rate for obese patients was 84.7%. Hematuria requiring blood transfusion (3.2%) and septicemia (2.1%) were the most common major complications in the obese and morbidly obese group. The complication rate and length of hospital stay were similar to those for the nonobese group. They concluded that PCNL is a feasible and effective procedure in obese and morbidly obese patients as well as nonobese counterparts [36].

Traditionally, PCNL has been performed in the prone position. This position facilitates posterior access to the collecting system through Brodel's avascular renal plane without causing significant parenchymal bleeding, peritoneal perforation, and visceral injuries. However, prone PCNL often causes respiratory system problems due to restriction of the patient's chest movement, and surgery may not be sustained in this position. The anesthesiologist and surgeon generally struggle to use this posiion in morbidly obese patients due to compromised cardiopulmonary status and body weight.

Increased knowledge of renal anatomy and clinical experience with PCNL have encouraged urologists to modify the prone position in an effort to improve results and overcome these limitations. The more recent literature has focused on alternatives in patient positioning, widening patient selection, or new techniques (i.e. tubeless PCNL). Gofrit *et al*. described lateral decubitus positioning for PCNL in morbidly obese or kyphotic patients [38]. Valvadia *et al*. first described PCNL in the supine position for patients with high anesthesiologic risk [39] and several authors have reported their experiences [40–45] (see Chapter 10). The supine position has several advantages, such as decreasing anesthetics requirement, preventing respiratory system-related complications, and allowing a simultaneous retrograde URS approach. In addition, urologists are more comfortable adopting a sitting posture during stone management. Difficulties in filling the collecting system against gravity, the small surgical field for nephroscopic maneuvers, difficulties in advancing the needle into the upper calyx are some limitations of supine PCNL. A randomized prospective study comparing the outcomes of PCNL in the supine and prone position reported treatment success rates of 77% and 80%, respectively [46]. In a comprehensive review, de la Rosette *et al*. emphasized that prone PCNL appears to be the more feasible with decreased operative times, similar bleeding rates, and slightly better stone-free rates than supine PCNL [47]. In contrast, Manohar *et al*. reported that the stone-free rate of supine PCNL in high-risk and morbidly obese patients was 95% [42]. Although the supine position seems to have some advantages for obese and morbidly obese patients and patients with staghorn calculi, the prone position has better outcomes over the supine position.

Percutaneous access into the pelvicalyceal system can be more difficult in obese patients. Some modifications have been reported to overcome this difficulty. Grasso *et al*. reported a technique of passing a flexible ureteroscope to capture the percutaneously inserted guidewire and establish through-and-through access at the beginning of the procedure [48]. Additionally, morbidly obese patients generally have excessive subcutaneous and fatty tissues and as a result standard PCNL instruments are too short to reach the stone. Segura described a technique to incise the skin and fat, with incision extending down to the muscular fascia, reducing the length required to reach the stone [49]. Giblin *et al*. reported the use of a long Amplatz sheath in combination with a 30F gynecologic laparoscope, which has a working length of 27 cm, to treat stones in morbidly obese patients [50]. In addition, choosing the shortest tract for percutaneous access and using longer devices, such as an Amplatz sheath longer than 17 cm and longer nephroscope, may facilitate the procedure. Moreover, using a ureteroscope through the percutaneous site may be helpful. Another technical problem specifically encountered in obese patients is the migration of the Amplatz sheath beneath the skin or muscle fascia (Figure 57.1). Bugeja *et al*. described a simple technique that makes use of a modified 10-mL syringe barrel to facilitate retrieval of a migrated access sheath in obese patients during PCNL [51]. We recommended using two sutures on the Amplatz sheath to prevent it from lodging under the skin (Figure 57.2). In this situation, these sutures allow the sheath to be pulled back out of the skin, either manually or using the open jaws of the grasping forceps (Figure 57.3). If all these techniques fail, a Foley catheter can be inserted into the sheath (Figure 57.4), and the sheath then pulled out after

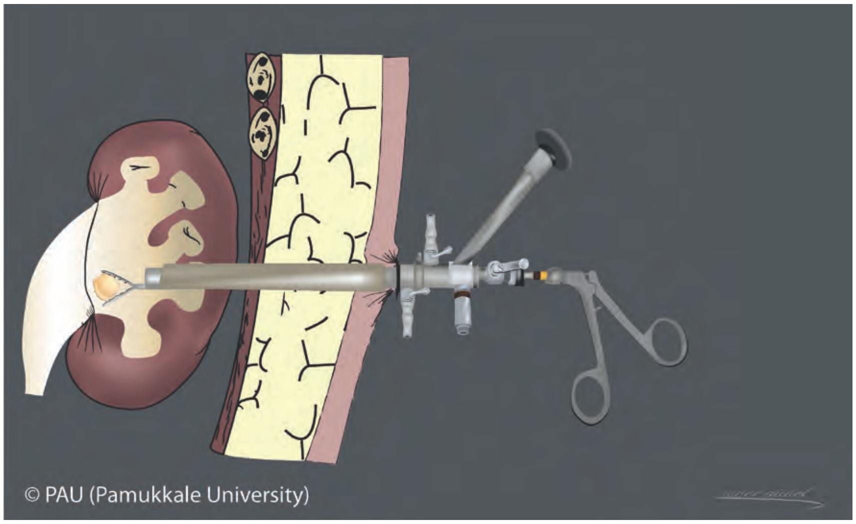
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Figure 57.1 Migration of the Amplatz sheath beneath the Skin during percutaneous nephrolithotomy in an obese patient.

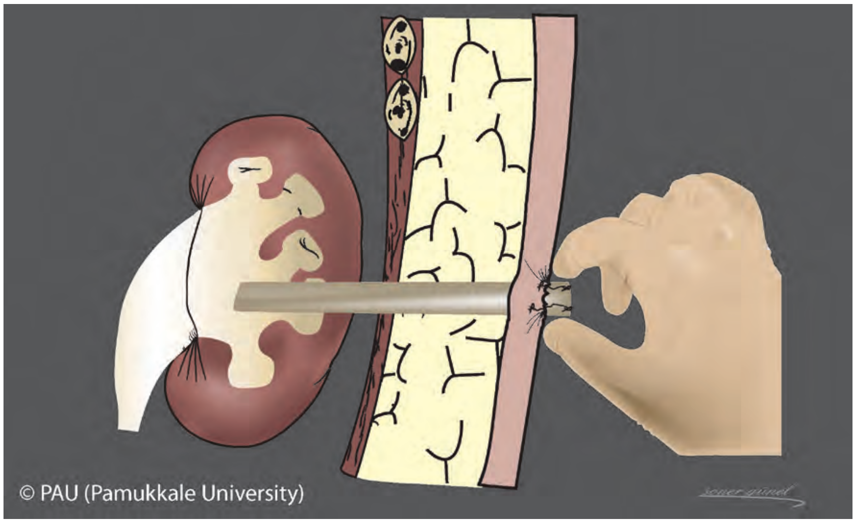
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Figure 57.2 Two sutures on the Amplatz sheath help prevent it from becoming lodged under the skin.

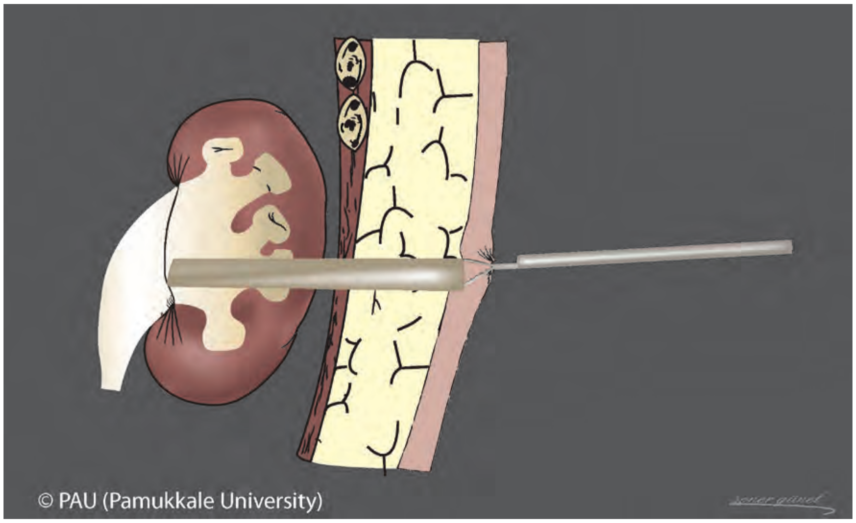
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Figure 57.3 Using the open jaws of grasping forceps to retrieve the Amplatz sheath.

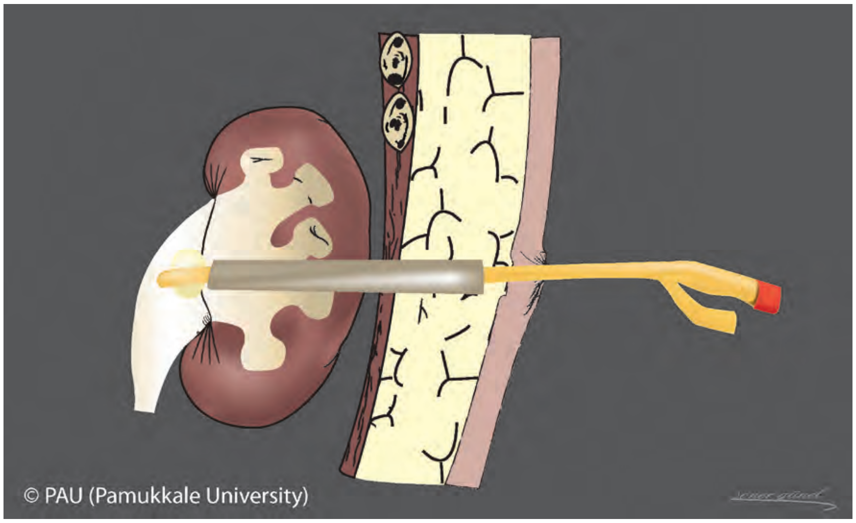

Figure 57.4 Inserting a Foley catheter into the Amplatz sheath facilitates withdrawal of the sheath once the balloon has been inflated.

Table 57.2 Tips and tricks for percutaneous nephrolithotomy in obese patients.

Use long Amplatz sheaths and nephroscopes
Choose the shortest possible tract
Stitch two sutures on the Amplatz sheath
Use the supine position in selected patients (for ventilation problems)

inflating the balloon. Tips and tricks for PCNL in obesity are listed in Table 57.2.

The surgical steps of standard prone PCNL in an obese patient are demonstrated in Video 57.1.

Conclusions

Epidemiologic studies indicate that obesity increases the risk of urolithiasis. Several pathophysiologic mechanisms have been proposed for abnormalities in urine composition in obese patients. These include carbohydrate-induced calciuria, increased protein intake, effects of insulin resistance on renal ammonia metabolism and urine pH, increased prevalence of gout and hyperuricosuria, or some other unidentified abnormality in renal electrolyte transport. Dietary modifications have an important role because metabolic abnormalities are more common in obese stone formers. Medical treatment has been shown to reduce the risk of stone formation.

Obesity poses a number of problems in the management of stone disease from diagnosis and imaging through to anesthesia and surgery. Comorbidity will be increased and anesthesia will need special expertise in this group of patients. ESWL has some limitations in morbidly obese patients in terms of table weight limit and focusing the stone. Several techniques have been described to overcome these limitations in some patients. Flexible URS technology is gaining worldwide acceptance because it allows rapid and high stone clearance rates. The PCNL technique can be modified in obese patients, providing similar outcomes and morbidity to those in nonobese patients. To manage the obese patients with urolithiasis safely and effectively, the urologist should have knowledge and experience of the potential diagnostic and treatment problems, as well as modifications of the techniques.

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CHAPTER 58

Management of Residual Stone Fragments

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Introduction and definitions

Residual stone fragments (RFs) represent a common and still controversial problem of shock-wave lithotripsy (SWL), percutaneous nephrolithotomy (PCNL) and ureteroscopy (URS). Still, the definition of RFs has not been well established. In the era of open stone surgery, RFs of any size suggested a failed procedure. With the advent of SWL, all fragments remaining in the kidney 3 months after the last session of SWL are defined as RFs [1]. Fragments larger than 5 mm are generally considered to indicate a failure of SWL [2]. Any fragments remaining following PCNL or URS are considered as RFs. The issue of RFs becomes more complicated with the introduction of the term "clinically insignificant residual fragments (CIRF)." The definition of CIRF that has prevailed describes post-treatment stones that are smaller than 4–5 mm, asymptomatic, nonobstructive, noninfectious, and associated with sterile urine [2–4]. The choice of size limit of less than 4–5 mm has not been based on solid statistical observations from previous studies.

RFs may be important for several reasons. They may act as a nidus for recurrent stone growth, especially when underlying metabolic abnormalities persist; they can become dislodged acutely and cause significant obstruction with pain; or they may be the source of persistent infection [3]. In patients with infection-related calculi, the consequence of RFs can be particularly harmful. RFs may harbor the offending bacteria and thus perpetuate postoperative bacteriuria and persistent infection. Furthermore, stone regrowth has been reported in up to 75% of such patients after SWL, compared with 10% of patients who experienced complete stone removal [5, 6]. For patients with metabolic stone disease, complete stone removal does not prevent stone recurrence, but it does prolong treatment intervals [7]. Thus, residual stones in these categories, including small stones, may not have an immediate clinical relevance but are likely to affect a patient's well-being in the long term. In these situations, it is important to select the treatment approach that is most likely to render the patient stone free.

We will review the natural history, identification, and treatment options for RFs following SWL, PCNL, and URS in the modern endourologic era.

Residual stone fragments following shock-wave lithotripsy

Outcome

Several studies have stressed the fate of RFs after SWL (Table 58.1) [5, 6, 8–15]. For a mean follow-up range between 6 and 57 months, spontaneous stone passage was noted in 11–92.7% of cases. The spontaneous clearance rate was highest for stones located in the ureter and lowest for the lower pole stones. Stones remained stable in 11–52.6%, while stone regrowth was encountered in 2–78%. This wide spectrum of results is attributed to the nature of the studies, most of which presented retrospective experiences. In addition, there were differences in the studies between methods of reporting treatment

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Table 58.1 Fate of residual stone fragments following shock-wave lithotripsy.

Series	Number of patients	Mean follow-up in months (range)	Stable (%)	Regrowth (%)	Stone free (spontaneous passage) (%)
Beck and Riehle [5]	53	26.6	11	78	11
Moon and Kim [8]	248	6	–	–	92.7
Streem *et al.* [9]	160	23 (1.6–88.8)	43.5	10	46.5
Buchholz *et al.* [10]	55	54	12.7	2	85.3
Zanetti *et al.* [6]	129	12 (3–12)	43.5	10	46.5
Candau *et al.* [11]	83	40.6 (7–96)	29	37	34
Khaitan *et al.* [12]	81	15 (6–60)	17.3	58.7	24
Afshar *et al.* [13]*	26	46	31	69	–
Osman *et al.* [14]	76	57 (52–63)	27.3	21.4	51.3
El-Nahas *et al.* [15]	154	31 (7.3–80.2)	52.6	33.8	13.6

*Pediatric population.

results, radiologic evaluation of residual stones, site and size of the residual stones, and timing of record of patients' follow-up data (1 vs 3 months) after the last session of SWL.factors Rassweiler *et al.*, in an extensive review of the literature, reported that 25% and 55% of patients with CIRF would be stone-free or the CIRF remain clinically insignificant during follow-up, respectively, 20% of CIRF would become clinically significant, and 4–25% of patients would require a secondary intervention which mostly would consist of a repeat SWL. The authors concluded that if there are no clinical symptoms, any endoscopic procedure should be considered as overtreatment [4].

The natural history and clinical significance of small, asymptomatic, noninfection-related stone fragments after SWL were prospectively evaluated in four studies [9, 10, 12, 14]. In total, 463 patients with CIRF of less than 5 mm in diameter were prospectively followed for a mean period of 15 months [12] to 4.9 years [14]. Stone-free status or a stable or increased amount of residual stone ranged from 23.8% to 78.9%, 10.7% to 41.9%, and 2% to 58.6%, respectively, and 41.4–100% of patients remained asymptomatic, while 0–58.6% had a symptomatic episode or required intervention 1.6–85.4 months after SWL. The intervention required was relatively noninvasive and consisted of either repeat SWL or retrograde endoscopy. As the stone burden and number of stone fragments increased, and when the fragments were located in the lower calyces, the risk of CIRF becoming clinically significant increased [9, 12, 14]. Also, as the duration of follow-up increased, the rate of complications increased [12]. Metabolic defects, when treated adequately, did not increase the regrowth rate [12, 14]. The results of these studies indicate that while patients with small CIRF after SWL can be followed expectantly, a significant number will require intervention or have symptomatic episodes during follow-up. As a consequence, the term CIRF after SWL may not be appropriate.

Diagnosis

There are no widely accepted guidelines regarding post-SWL imaging and follow-up. For radio-opaque stones, most urologists order a kidney, ureter, and bladder (KUB) X-ray, and for radiolucent stones a computed tomography (CT) scan or ultrasound is required. The timing of post-SWL imaging also varies widely from center to center. Many endourologists feel that there is no role for routine imaging less than 3 months post SWL because stone fragments may take several weeks to pass after SWL. Unenhanced helical CT (UHCT) has been shown to be superior to other imaging modalities in its ability to identify the presence of urinary calculi in general. In a prospective study, CT had a sensitivity of 97%, specificity of 96%, and accuracy of 97% for revealing urinary stones [16].

Data from several prospective studies of UHCT overwhelmingly support CT as the best method for diagnosing the presence of urinary stones when compared to ultrasound, ultrasound combined with plain X-ray films, intravenous urography (IVU), and magnetic resonance urography (MRU) [17–21]. A recent meta-analysis showed that CT scan is better than IVU for the detection of urinary stones. There is little difference in the radiation dose and patient acceptability for each test [22, 23].

The ability of UHCT to detect small renal calculi is significantly affected by section width, particularly when stone fragments are smaller than 3.0 mm. Section widths of 1.25 and 2.5 mm were able to show renal stones significantly better than thicker reconstructions. Specificity was not significantly affected by section width in a recent study of Jin *et al.* [24]. In contrast, sensitivity increased as stone size increased and as section width decreased. Sensitivity for the detection of all stones was 80.7%, 80.7%, 87.7%, and 97.7% for 5.0-, 3.75-, 2.5-, and 1.25-mm section widths, respectively. Nevertheless, thinner section widths create more images for evaluation and increase image noise, potentially increasing the false-positive rate [24].

When an RF is found, CT can also provide excellent information about its size, location, and composition, providing the urologist with critical information for planning treatment. Therefore, it can be suggested that the literature supports that CT be utilized in preference to other imaging modalities for patients with suspected RFs following SWL. Improvements in CT technology with the development of low-dose protocols, dual-source CT, and micro CT, while maintaining quality of imaging for diagnosing stones, will eventually replace other imaging modalities in the diagnosis of RFs following SWL [25–27].

Surgical management

In the past, several authors have not recommended systematic SWL retreatment for all asymptomatic patients with RFs after an initial session of SWL [4, 6, 10, 28]. With the exception of the study performed by Buchholz *et al.* [10], the above recommendation emerged from the results of reviews or retrospective studies. Buchholz *et al.*, in a study of 55 patients with CIRF, showed that only 12.7% of the RFs had not passed spontaneously after a mean follow-up of 2.5 years [10]. All were clinically silent and only in 2% of the cases was stone regrowth seen. No stone recurrences were observed within the follow-up period. The authors concluded that more invasive procedures to clear all minor fragments are not warranted. However, with emerging evidence showing that the term CIRF could be a misnomer, mainly due to the fact that a great proportion of patients will require an intervention as the follow-up increases [9, 10, 12, 14], several authors have addressed the issue of early retreatment of RFs after an initial intervention [8, 29–32].

Parr *et al*. in a retrospective study showed that additional SWL for CIRF remaining after a mean of two (range one to nine) initial SWL sessions, promoted stone clearance only in those patients with nondilated calyces [29]. The small number of patients included in the study (n = 22), the small number of patients who benefited from retreatment (n = 3), and the nature of the study do not allow definitive conclusions to be drawn. In a retrospective study by Moon *et al.*, the stone-free rate for 248 cases of CIRF was 32.7% at 1 month, 73.0% at3 months, and 92.7% at 6 months of follow-up [8]. Of 16 patients who had RFs at 6 months and who underwent an additional session of SWL, 12 (75%) became stone free by another 6 months of follow-up. The authors suggested that repeated SWL, even for stone fragments of 3–4 mm in diameter, might promote clearance of the CIRF. This was confirmed in a prospective randomized study conducted by Krings *et al*. [30]. Piezoelectric SWL retreatment was compared to surveillance only in 50 patients with persistent calyceal stone fragments after primary SWL for renal calculi. After 3month follow-up, significant decreases in residual debris were observed in the retreated group, while changes in the control group were negligible. The authors suggested that, considering the low morbidity of outpatient SWL with a pain-free, second-generation lithotripter, SWL retreatment of completely fragmented but persistent stone debris appears to be justified to render the kidney stone free. Still, the advantages of a higher stone-free rate from SWL retreatment must be weighed against potentially higher side effects and the additional cost.

An adjunct to the clearance of lower pole calculi after SWL has emerged in the form of mechanical percussion and inversion with or without diuresis [33]. In this study by Chiong *et al.*, 108 patients with lower pole calculi of 2 cm or smaller were prospectively randomized to undergo SWL alone or SWL followed by mechanical vibration, inversion, and diuretic therapy [33]. The radiologically documented complete stone clearance rate at 3 months for the first group was 35.4%, while for the second group it was 62.5% ($P = .006$). The same treatment modality has been applied in a prospective randomized manner for CIRF after SWL [31]. Pace *et al*. compared the effectiveness of mechanical percussion and inversion with observation for 1 month, for eliminating calyceal fragments of less than 4 mm 3 months after SWL. The mechanical percussion and inversion group had a substantially higher stone-free rate (40% vs 3%, $P < 0.001$) and a greater improvement in total stone area (−63.3 vs +2.7%, $P < .001$) than the observation group. No significant adverse effects were noted in either group. The authors stated that mechanical percussion and inversion is a safe and effective treatment option for residual lower pole calculi.

Medical treatment

Metabolic evaluation and stone analysis should be offered to patients who require surgical stone removal. Pearle *et al.* have emphasized the importance of the administration of medical therapy in reducing stone recurrences after treatment [34]. In their meta-analysis of randomized trials for medical prevention of nephrolithiasis, they showed a significant benefit of drug therapy for calcium oxalate stones. This was mainly attributed to the benefit of using thiazides compared to placebo or no treatment. The variability in design of the analyzed studies precluded adequate analysis of other drug therapies such as alkaline citrate or allopurinol.

Table 58.2 Effect of medical therapy on residual stone fragment activity.

	Stone free (%)		Stone size unchanged or decreased (%)		Stone size increased (%)**	
Study	Medical therapy	Control	Medical therapy	Control	Medical therapy	Control
Cicerello *et al.* [37]*	80.5	36	75	52.6	5	47
Soygur *et al.* [38]*	44.4	12.5	56.6	25	–	62.5
Sarica *et al.* [39*†	–	–	81.8	27.2	18.2	72.8
Fine *et al.* [36]	58.3	38.4	13.9	0	27.8	61.6
Wang *et al.* [41]***	85/80	82	–	–	–	–

*Randomized controlled study.
**Regrowth and/or recurrence rate included.
***Patients randomized to tamsulosin, terazosin or placebo.
†Study in children.

Medical therapies, in addition to preventing stone recurrences, have been reported to ease urinary stone passage [35]. Hollingsworth *et al.* have published the results of a meta-analysis of all randomized controlled trials in which calcium channel blockers or alpha-blockers were used to treat urinary stone disease [35]. Their findings, extracted from nine trials encompassing 693 patients, suggested that medical therapy is an option for facilitating urinary stone passage for those patients amenable to conservative management, potentially obviating the need for surgery. Patients given calcium channel blockers or alpha-blockers had a 65% greater likelihood of stone passage than those not given such treatment. The pooled risk ratio for alpha-blockers was 1.54 (1.29–1.85) and for calcium channel blockers with steroids was 1.90 (1.51–2.40). The proportion of heterogeneity not explained by chance alone was 28%. The number needed to treat was 4.

Several authors have addressed the issue of medical therapy in the management of RFs after SWL [36–39] (Table 58.2). Fine *et al.*, in a retrospective nonrandomized study, evaluated the fate of RFs after SWL in regard to whether the patients were or were not put on medical therapy after the procedure [36]. Of the 49 patients identified with RFs after SWL, 36 received medical therapy in the form of thiazide diuretics, sodium cellulose phosphate, allopurinol, potassium citrate, and α-mercaptopropionylglycine, based on specific indications. Thirteen patients chose to stop medical treatment within 4 months after SWL. Patients on medical therapy experienced a significant decrease in the stone-formation rate from a median of 1.17 to 0.00 stones/patient/year ($P < .001$). In those patients not on medical therapy, there was only a minimal decrease in the stone-formation rate from a median of 1.33 to 0.77 stones/patient/year. The medically treated patients had a significantly greater stone remission rate than the untreated patients (63.9% vs 23.1%, $P < 0.05$), while stone burden increased in 27.8% and 61.6%, respectively. Moreover, while 13.9% of the treated patients demonstrated a decrease in stone burden, none of the untreated patients showed a decrease in stone mass. The authors specifically assessed the significance of CIRF (stones < 5 mm in diameter). Among the 49 patients, 36 had CIRF, and 25 of these received medical therapy while 11 did not. Fragment growth was seen in 16% of those treated medically compared to 54.5% of the untreated patients ($P < .05$). This retrospective study indicated that early medical therapy may control active stone formation in patients with RFs following SWL [36].

These results were confirmed by three prospective randomized trials. Cicerello *et al.* showed that citrate intake reduced growth or agglomeration and increased the clearance rate of RFs after SWL in calcium oxalate and in infection stone patients [37]. The authors prospectively randomized 40 sterile calcium and 30 struvite stone patients with RFs of less than 5 mm in diameter after SWL into two groups: one on citrate therapy (6–8 8 g/day) and the other on hygienic measures only, the latter serving as the control group. Infection stone patients also received adequate antibiotic therapy throughout the study. After 12-month follow-up, RFs disappeared in up to 74% of the citrate-treated calcium oxalate patients and up to 86% of the citrate-treated infection stone patients. In the control group, the rates were 32% and 40%, respectively. During the 12-month follow-up, RF growth or reaggregation occurred in 47% of the calcium oxalate control patients compared to 5% of the calcium oxalate citrate-treated patients. None of the treated or control infection stone patients in whom stone fragments persisted at the end of follow-up had growth or reaggregation of RFs [37].

Similar results were found in the study by Soygur *et al.*, who prospectively randomized 34 patients with lower pole RFs after SWL into two groups that were matched for sex, age, and urinary levels of citrate, calcium, and uric acid [38]. One group was given oral potassium citrate 60 mEq/day and the other group served as controls. The stone recurrence rate at 12 months in the group who were on citrate therapy was significantly less than in the control group (56.6% vs 87.5%, respectively). Stone fragments disappeared in eight (45.5%) and remained the same size in 10 of the 18 patients (54.5%) who continued medical therapy. In the control arm, RFs disappeared in only two (12.5%) and remained unchanged in four (25%) of the 16 patients [38].

Medical treatment also appears to prevent stone regrowth or stone formation in children with RFs after SWL. Sarica *et al*. randomized 44 children in whom stones of less than 5 mm in diameter persisted after SWL into two groups [39]. Group I (n = 22) received potassium citrate 1 mEq/kg/day for 12 months under close follow-up. Group II (n = 22) received no specific medication or preventive measure and constituted the control group. Children on medication showed significantly lower regrowth and recurrence rates compared to children in group II [four of 22 (18.1%) vs 16 of 22 (72.7%), respectively]. Moreover, the mean size of the RFs in patients receiving no therapy demonstrated a significant increase from baseline compared with the children on medication. Whereas the mean size of the RFs in group II was 3.6 mm 1 month after SWL, it was 5.4 mm after a year ($P < 0.05$). There was no significant change in children undergoing potassium therapy, with mean sizes of 4.0 mm before medication and 4.4 mm at 1 year ($P > 0.05$) [39].

Medical expulsive therapy to enhance the stone-free rate following SWL has recently been questioned. This was triggered by a recent double-blind, placebo-controlled randomized trial which showed that tamsulosin treatment does not improve stone expulsion rate in patients with distal ureteral stones of less than 7 mm [40]. Subsequently, Wang *et al*. randomized 107 patients who had been treated with SWL for lower ureteral stones into three groups. The first group received tamsulosin, the second terazosin, and the third placebo after the SWL. The administration of an alpha-blocker reduced analgesic dosage and colic episodes after SWL of lower ureteral stones. There was no benefit with regard to increasing stone expulsion rate or decreasing expulsion time (Table 58.2) [41]. Large-scale, well-designed randomized studies will eventually elucidate the role of adjunctive medical therapy following SWL.

Residual stone fragments following percutaneous nephrolithotomy

Natural history

Assessment of stone clearance after PCNL is based on the endoscopic appearance of the collecting system at the completion of the procedure [3, 42, 43]. Stone-free rates have been reported to range from 40% to 90%, depending on the size, number, composition, and nature (i.e. staghorn, infectious) of the stone, as well the surgeon's skills [44, 45]. Reasons for failure of complete clearance during PCNL include poor visualization secondary to bleeding, inability to access a fragment-containing calyx, and the subjective impression of prolonged operative time. Improper selection of the surgical technique as well as anatomic abnormalities, stone composition, and technical constraints may influence the number and size of RFs versus a stone-free status [3].

In a study by Ramana *et al.*, of 537 patients who were followed up after PCNL with UHCT, 42 (8%) patients were diagnosed with RFs [42]. The anatomic distribution of RFs was 47% lower, 32% mid, 24% upper pole, and 18% renal pelvis/ureter. The median diameter of the largest RF was 2 mm, with 60% (25 of 42) of fragments 2 mm or smaller and 79% (33 of 42) smaller than 5 mm. All 42 patients with RFs were under surveillance and 18 (43%) of them experienced a stone-related event with a median time to occurrence of 32 months. A stone-related event is defined as growth of a RF or need for emergency consultation, hospitalization, or additional intervention specifically aimed at alleviating symptoms, obstruction, and/or removing the RF. The authors reported that of the 18 patients who experienced a stone-related event, 11 (61%) required a secondary surgical procedure. Fragments with a maximum diameter greater than 2 mm and those located in the renal pelvis or ureter independently predicted a future stone-related event. In addition, more than half the patients with an RF larger than 2 mm required a second-look flexible nephroscopy, underscoring the importance of maximum RF size in comparison with cumulative RF size.

In another study evaluating the fate of residual stones after PCNL, RFs of less than 25 mm^2 and those situated in the renal pelvis again had the best chance of clearance. Approximately half the RFs passed spontaneously, and the majority was cleared in 3 months. The size of the residual stone, history of intervention, renal failure, and metabolic hyperactivity were predictors of persistence of RFs [46].

Significance of residual fragments

The term "CIRF left after PNCL" defines RFs of similar characteristics to CIRF after SWL [3, 47]. Recently, Osman *et al* introduced the term "CT clinically insignificant RFs," including one or two gravels less than 5 mm, as measured by post-PCNL UHCT [48]. We feel that these terms may lead to the acceptance of treatment failures and minimize the clinical significance of RFs after PCNL.

There is no reason to believe that RFs after PCNL will behave differently from RFs after SWL. However, the clinical scenarios are nonetheless significantly different. Removal of RFs after SWL requires either additional SWL or more likely, an invasive surgical intervention. In contrast, removal of RFs diagnosed after PCNL may involve a second procedure (i.e. flexible nephroscopy) through a pre-existing tract. Furthermore, there is theoretical concern that the rate of stone formation may be greater following SWL compared to PCNL because of microscopic residual stone debris left in the collecting system acting as a nidus for stone crystallization. Carr *et al.* demonstrated a significantly greater rate of stone formation within 1 year after treatment with SWL compared to PCNL [47]. Stone recurrences for the SWL group showed a shift from baseline location before treatment to a greater likelihood for recurrence within mid and lower calyces. A similar trend was not observed in the PCNL group. An explanation for these results would be that fine sand debris gravitate to dependent calyces and act as a nidus for stone growth. SWL, by dramatically increasing the surface area of the original stone, may favor new stone growth through heterogeneous nucleation and crystal aggregation.

Prevention

Fragmentation and removal parameters

The impact of single and multiple pulse settings of pneumatic lithotripsy on creating RFs during PCNL has been addressed in a prospective study [49]. The single pulse mode was associated with controlled fragmentation of the stone, formation of larger fragments which were easier to pick up, less stone scatter, shorter operating time (124.1 min vs 141.2 min), less exposure to fluoroscopy (5.8 min vs 7.4 min), and statistically less chance of RFs (16 cases vs 35 cases).

Multitract PCNL for large staghorn stones could potentially reduce the incidence of RFs. Such a technique has been demonstrated as feasible, safe, and effective in a study of 121 renal units with complete staghorn stones [50]. There are a number of graspers and baskets available to snare and remove stones during PCNL. Flushing out the collecting system, once stone fragments have been identified as of a size that can pass through the Amplatz sheath, may further reduce the number of potential RFs [51].

Instruments preventing fragment migration

During PCNL, stone fragment migration remains a concern, especially if it occurs into the ureter, as additional procedures are then necessary. Deploying the Stone Cone® (Boston Scientific, Natick, MA, USA) just below the ureteropelvic junction obstruction has been shown to prevent migration of stone fragments into the ureter during PCNL [52]. This maneuver may reduce the need for antegrade URS to remove RFs, thereby saving time and obviating the need for placement of an occlusion ureteral balloon. It would be interesting to study the feasibility and efficacy of placing such an instrument in those calyces where protection from migrating fragments is particularly desirable, i.e. the upper pole in case of lower pole access.

Diagnosis

Plain X-ray KUB, linear tomography, and ultrasound have all been used to judge the result of PCNL and to detect the presence of RFs. However, the superimposition of bowel gas, feces, and soft tissue calcifications, as well as the presence of obesity, faintly radio-opaque stones, nephrostomy tubes and/or pigtails decrease the accuracy of these diagnostic modalities [3, 53, 54].

When thin-slice UHCT, in conjunction with image reconstruction, was prospectively compared to other imaging modalities, it showed higher sensitivity for the detection of RFs [44, 48, 55]. The sensitivity of the UHCT reached 100% [55] compared to 47.6–82.1% [44, 55] for X-ray KUB, 89.2% for linear tomography [55], and 67.8% for ultrasound [55]. The mean size of stones missed by KUB films was 7.4 mm, with 45.5% of stones being greater than 4 mm in diameter [44]. When the outcome of detecting RFs is stratified by stone density and stone size, UHCT sensitivity appears to be even higher for faint, lucent, and small stones compared to the sensitivity of other imaging modalities [56]. The sensitivity for overall detection of opaque stones was 100%, 62.9%, and 74.3% for UHCT, KUB, and ultrasound, respectively. In contrast, for faint and lucent stones, the rates were 100%, 11.1%, and 22.2%, respectively. While UHCT detected small stones efficiently, in cases of more than one or two opaque calyceal RFs greater than 4 mm, it did not show a statistically valuable increase in the diagnosis compared with KUB and linear tomography. In addition to higher sensitivity, UHCT reduces the total cost required to render patients stone free by reducing the need for second-look flexible nephroscopy in every patient [56].

The ultimate time to perform post-PCNL UHCT is debatable. The end of the first month after surgery is regarded as the optimal timing, taking into consideration that earlier imaging may produce false-positive results from inconsequential dust and may detect RFs that pass spontaneously during the immediate postoperative period [57]. Also, imaging at 1 month has advantages over more immediate imaging because RFs may be obscured by nephrostomy tubes and/or ureteral stents. Under these circumstances the use of bone window during UHCT may be needed to differentiate between a kidney stone (<1600 HU) and the stents/tubes (>1600 HU) [58].

Management

Is there still a role for shock-wave lithotripsy and "sandwich" therapy?

When PCNL is compared with combination therapy, stone-free rates are higher with PCNL (78% vs 66%), PCNL requires fewer total procedures (1.9 vs 3.3), and transfusion rates are similar for the two modalities (18% vs 17%) [43, 59–61]. Combination therapy is being used less frequently as a result of improvements in endoscopic and intracorporeal lithotripsy technology. Multitract PCNL [50], repeat PCNL or second-look nephroscopy [61] through an established tract may prove more efficient for reducing RFs post PCNL.

Second-look flexible nephroscopy

As demonstrated when the natural history of RFs was evaluated, second-look flexible nephroscopy may benefit patients with RFs larger than 2 mm or those with RFs located in the renal pelvis or ureter [42]. The use of second- and third-look flexible nephroscopies resulted in a 97% stone-free rate in a pediatric population [62].

It is likely that some patients may not have RFs or may pass these spontaneously, making second-look flexible nephroscopy an unnecessary and expensive procedure. Aggressive stone clearance during initial PCNL may obviate the need for routine second-look nephroscopy [63]. Furthermore, careful intraoperative evaluation of stone-free status may lead to avoidance of unnecessary second-look flexible nephroscopy. The intraoperative determination of stone-free status, made prospectively by the combination of the intraoperative radiologic and endoscopy findings, led to negative predictive values of 100%, 88%, and 73% at postoperative CT fragment detection thresholds of 4 mm, 2 mm, and 0 mm, respectively [64]. Nephrostomy tubes were avoided in 44.5% of the patients. Finally, postoperative imaging may reduce the need for second-look flexible nephroscopy by reliably identifying patients without residual stones. An unnecessary flexible nephroscopy would have been avoided by positive UHCT findings in 20% of patients, resulting in significant cost savings of US$109 687 per 100 patients [56].

Ureterorenoscopy

Flexible URS can be considered for the management of patients with post-PCNL RFs [65–67]. Initial clinical experience with digital flexible URS revealed remarkable improvement in image quality as well as zoom capability; however, relevant comparative studies are surprisingly scant and are warranted.

Combined PCNL and flexible URS can effectively increase stone-free rates without increasing morbidity [68–70]. In order to treat RFs after PCNL for a staghorn stone, Undre *et al.* described a technique of synchronous percutaneous nephroscopy and retrograde flexible URS [71]. Two surgeons worked in parallel, one to fragment and relocate the RFs to the pelvis and the other to retrieve them from the mature nephrostomy tract.

Interestingly, a rigid ureteroscope can be used to remove post-PNL RFs. Goel *et al.* described a simple technique of RF removal in patients who underwent PCNL and had a nephrostomy tube *in situ* [72]: under local anesthesia and sedation, a rigid 8.5F ureteroscope was introduced through the nephrostomy tube and the RFs were retrieved. However, this technique is indicated in patients who have RFs of less than 5 mm and located in the same calyx or pelvis as the tip of the nephrostomy tube.

Medical treatment and percutaneous chemolysis

There is some evidence suggesting that medical management, including potassium citrate for hypocitraturia, renal tubular acidosis, chronic diarrhea syndromes, and gouty diathesis; thiazide diuretics for hypercalciuria; and allopurinol for hyperuricosuria, can control active stone formation in patients with RFs after PCNL [73]. Patients on medical therapy exhibited a lower median stone-free rate (0.02 vs 1.00 stones/patient/year) and a higher remission rate (77% vs 21%) compared to patients not on medical therapy, supporting the role of medical treatment in inhibiting new stone formation or growth in patients with RFs following PCNL [73].

Antegrade chemolysis also may have a role in treating RFs after PCNL; however, it has the drawback of prolonged hospitalization, side effects, and increased cost. The ideal chemolysis system should consist of dual nephrostomy tubes (inflow and outflow) and an indwelling ureteral catheter to guarantee passage of RFs [3]. Emphasis should be placed on outflow drainage of the irrigant to keep intrapelvic pressures below 25 cmH_2O. Also, it is important to know the composition of the stone to be treated, in order to choose the appropriate irrigant.

Percutaneous chemolysis with "Suby G" solution may dissolve struvite and apatite stones, but is ineffective in cases of whewellite and weddelite stones [74]. Radiolucent uric acid stones can be successfully disintegrated during percutaneous chemolysis with a 0.1 M sodium bicarbonate solution [75]. Potential side effects such as fever are usually managed conservatively without severe sequelae. In cases of struvite stones, patients should be closely monitored as there is a risk of urosepsis.

Residual stone fragments following ureteroscopy

Natural history

Since its first description over 20 years ago, URS has progressed from an awkward diagnostic procedure with limited visualization to a precise, complex surgical intervention allowing access to the entire collecting system [76].

There is a paucity of studies specifically designed to evaluate the natural history and management of RFs following ureterolithotripsy. One possible explanation could be that with the development of smaller caliber semi-rigid and flexible ureteroscopes, and the introduction of improved instrumentation, including the holmium : YAG laser, URS has evolved into a safer and more efficacious modality for treatment of stones in all locations in the ureter with increasing experience worldwide [76].

The American Urological Association (AUA) and the European Association of Urology (EAU) have published combined guidelines for the treatment of ureteral stones, based on the meta-analysis of data published up to 2007. Table 58.3 shows the RF percentages extracted indirectly from the stone-free rates following URS when applied as a primary or first treatment choice [77]. Table 58.4 shows the same percentages based on the different types of URS applied. It is important to note that the vast majority of patients were rendered stone free in a single procedure [77].

The clinical significance of small stones remaining after URS is unknown. Indirect inferences can be drawn from studies evaluating the expectant management of ureteric calculi. Spontaneous passage of symptomatic single ureteral calculi is size and time dependent [78]. A meta-analysis comprising 2704 patients treated prior to the advent of SWL and URS showed that when comparing passage rates based on stone size, regardless of location in the ureter, stones of less than4 mm and greater than 6 mm had spontaneous passage rates of 38% and 1.2%, respectively [79]. More recent reviews reported that distal ureteral stones of less than 5 mm in diameter passed spontaneously with a rate of 71–100%, whereas stones of 5–10 mm in diameter passed with a rate of 25–46% [77, 80]. There is a roughly linear relationship between stone size and the likelihood of spontaneous passage, with reported passage rates of 87%, 72%, 47%, and 27% for stones measuring 1, 4, 7, and 10 mm, respectively [81]. Spontaneous passage rates are higher for distal ureteral stones (45–71%) compared with middle (22–46%) and proximal ureteral stones (12–22%) [79, 82]. Moreover, stones of less than 2 mm have a 4.8% chance of requiring intervention during surveillance compared to a 50% chance for stones of 4–6 mm [83].

Schatloff *et al*. were the first to evaluate in a prospective trial the natural history of small RFs remaining in the ureter following semi-rigid URS and holmium laser lithotripsy. Sixty patients were randomized to intraoperative RF retrieval or exhaustive lithotripsy and spontaneous RF expulsion. Patients with RFs, although less than 2 mm in diameter, were associated with a higher risk of unplanned medical visits at 30 days of follow-up. The reasons for a medical visit were renal colic and/or spontaneous stone passage. Patients had to be admitted due to renal colic, distal RFs, and fever or unresponsive

Table 58.3 Median percentage of patients with ureteral residual stone fragments when ureteroscopy was applied as a primary or first treatment option (AUA/EAU Ureteral Stones Guideline panel).

Overall population	G/P	%
Distal ureter	59/5952	6
<10 mm	13/1622	3
>10 mm	8/412	7
Mid ureter	30/1024	14
<10 mm	5/80	9
>10 mm	5/73	22
Proximal ureter	46/2242	19
<10 mm	9/243	20
>10 mm	8/230	21

G, number of groups/treatment arms extracted; P, number of patients in those groups.

Table 58.4 Median percentage of patients with ureteral residual stone fragments when different types of ureteroscopy were applied as a primary or first treatment option (AUA/EAU Ureteral Stones Guideline panel).

	All forms (%)	Flexible (%)	Mixed flexible (%)	Rigid (%)
Total ureter				
<10 mm	7	16	13	5
>10 mm	13	–	19	12
Proximal ureter				
Overall	19	11	13	23
<10 mm	20	16	17	23
>10 mm	21	–	19	19
Mid ureter				
Overall	14	12	12	15
<10 mm	9	–	13	8
>10 mm	22	–	40	20
Distal ureter				
Overall	–	–	–	–
<10 mm	7	16	13	5
>10 mm	13	–	19	12

renal colic. In one patient a nephrostomy tube and eventually ancillary URS were needed. Although the study was prone to methodologic drawbacks, it indicates for the first time that complete stone clearance should be the aim of every ureterolithotripsy [84].

Prevention

The creation of RFs is dependent mostly on the surgical technique. With the advent of the holmium laser the size of RFs was reduced significantly compared to ultrasound, pneumatic, pulsed dye laser or electrohydraulic lithotripsy. More fragments remaining after holmium laser lithotripsy are less than 2 mm, and these may not need to be actively extracted [85]. Differences in the holmium laser technique may result in different RF sizes. Careful vaporization may break the stone into minute fragments as opposed to an exhaustive lithotrpisy which may result in the accumulation of tiny stone fragments in the ureteral lumen that resemble a pile of dust. Clinically significant remnants may be easily missed and left untreated under these circumstances [84, 85].

Another technique to decrease RF size is to increase the laser frequency and shoot the stone in a noncontact fashion, creating the so-called popcorn effect [86]. Proximal stone or fragment migration accounts for significant URS failures [87]. It is associated with a shorter laser pulse length, wider fiber diameter, upper ureteral site, and small stone size. Performing lithotripsy at low energy with little irrigation and actively extracting each fragment as soon as it breaks from the stone may prevent stone migration [84]. Stone retropulsion can also be prevented by using a ureteral occlusion device, such as the Stone Cone® and NTrap®, or stone retrieval baskets such as the Escape™ [88, 89].

Traxer *et al*. have described various techniques of how to avoid accumulation of stone fragments in the lower calyx during flexible URS. Repositioning the stone to another calyx or pelvis, lower calyceal occlusion by autologous blood clot and flank position may also aid in retrograde calyceal stone treatment [90–93].

The impact of ureteral stenting on RF clearance following URS has not been evaluated. However, in a recent meta-analysis of all randomized controlled trials examining ureteral stent placement after URS, no difference in the outcome between patients with and patients without a stent was revealed [94]. There was a slightly lower absolute risk of complications associated with the placement of a ureteral stent after URS. Results from a matched-paired analysis have shown that ureteric stents may compromise stone clearance after SWL for ureteric stones [95]. Whether the same effect could be inferred to URS is unknown. Nevertheless, there are specific groups of patients, like those undergoing bilateral URS, those with urinary tract infections, and pregnant women, who are likely to benefit from stenting [96].

Diagnosis

Studies regarding follow-up after URS are controversial [97–101]. Routine imaging for follow-up has recently been questioned because of the low complication and high success rates of URS stone removal. Additional parameters against routine follow-up are the low percentage of patients suffering symptoms postoperatively, the high association of the presence of symptoms with the existence of residual stones leading to early diagnosis, and the low incidence of silent obstruction following URS. However, the latter is often associated with remaining stone fragments and may cause severe renal deterioration. In addition, there is some evidence that the majority of asymptomatic ureteral stones will pass spontaneously within 4 weeks from diagnosis. With further observation, symptoms and complications may appear in patients [79, 102]. In view of this evidence, most urologists advocate routine follow-up for RFs after URS [101].

The majority of the studies that report on the efficacy of URS use KUB plain radiography, ultrasonography, and/or intravenous urography. With these modalities URS stone-free rates for both renal and ureteral stones have been reported to be 77–81% [103, 104] and 91–100%, respectively [105–108].

Stone-free rates are significantly lower when CT scan is used for follow-up. These rates ranged from 50% to 54% in three studies evaluating the result of URS for lower pole stones of less than 1 cm or for renal and proximal ureteral stones [90, 109, 110]. Overall stone clearance rates increased to 62.8% and 84.1% when the threshold for ureteric success was lowered to allow stone fragments of 2 mm or less and 4 mm or less, respectively [110]. Stone-free rates are significantly higher for ureteral stones (80%) than renal stones (34.8%). Renal units with multiple stones are less likely to be rendered stone free (36.7%) than those with single stones (61%) [110].

Management

Although every possible effort should be made to retrieve stone fragments during URS to avoid future unplanned medical visits [84], it is not clear whether all fragments recognized postoperatively should be actively treated. Similar to post-SWL fragments, RFs larger than 4–5 mm after URS need to be treated with a secondary URS or SWL when located in the pelvis or calyces.

There is a paucity of studies on treatment for smaller RFs post URS. A recent study randomized, patients to active retrieval versus spontaneous passage of stones during holmium laser ureterolithotripsy [84]. In the latter group, the stone was completely turned into dust or fragments of less than 2 mm, which were left *in situ*. There was no statistical difference in hospitalization, need for pain analgesia, time to complete recovery, stone-free rate, and need for ancillary procedures at 30 days of follow-up. For stones sized between 2 and 5 mm, the existing evidence for spontaneous ureteric stone passage and the fate of RFs following SWL indicate that treatment should be individualized [77–83].

Conclusions

The definition of "clinically significant residual stone fragment" is based on arbitrarily set criteria. There is some evidence indicating that as the burden and number of clinically insignificant RFs increases, the risk of becoming clinically significant also increases. Moreover, as the duration of follow-up increases, the rate of complications and the need for intervention due to symptomatic episodes also increase. SWL retreatment, with or without patient inversion, of completely fragmented but persistent stone debris appears to be justified to render the kidney stone free following primary SWL. Medical therapy can control active stone formation, reduce growth or agglomeration, and increase the clearance rate of RFs after SWL.

RFs following PCNL can occur in up to 8% of patients. When left untreated, approximately half of these patients will experience a stone-related event, for which more than half will require a secondary surgical intervention. For these reasons, urologists should take all measures to prevent their creation, carefully identify their existence postoperatively, and actively deal with them by a second-look flexible nephroscopy and/or flexible URS. Medical therapy may control active stone formation and growth in patients with RFs after PCNL.

Patients with RFs following URS are associated with a higher risk of unplanned medical visits and a tendency towards higher rates of rehospitalization, residual stones, and the need for ancillary procedures. Appropriate stone disintegration and removal of all stone fragments should be the aim of every ureterolithotripsy. Using technology properly to avoid the creation of large RFs and to prevent stone migration may eventually decrease the RF rates. There is a paucity of studies on treatment for post-URS RFs. Evidence derived from the spontaneous ureteric stone passage and from the fate of RFs following SWL indicates that treatment should be individualized.

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CHAPTER 59

Management of Renal Colic and Triage in the Emergency Room

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Introduction

Acute renal colic is probably the most painful event a person can endure. Renal colic affects approximately 1.2 million people each year and accounts for approximately 1% of all hospital admissions. Most active emergency rooms (ERs) treat an average of at least one patient with acute renal colic every day, depending on the size of the hospital [1]. Renal colic is often the supposed diagnosis made in the ER in patients presenting with acute onset of flank or loin pain. Often, multiple investigations are done before the diagnosis is confirmed. Frequently this causes a delay in appropriate management. It is up to the attending physician or urologist not only to make the prompt diagnosis but also to initiate effective pain control and identify potentially complicated renal colic.

Classic presentation of renal colic: symptoms and signs

Patients with acute renal colic classically present with a sudden onset of severe pain originating in the flank. The initial presentation typically lasts 3–18 h. The progression of pain has been described as having three clinical phases. The typical attack starts slowly and insidiously. The pain is usually steady, increasingly severe, and continuous. The pain typically waxes and wanes in severity, and develops in waves or paroxysms that are related to movement of the stone in the ureter and associated ureteral spasm. Paroxysms of severe pain usually last 20–60 min. Pain is thought to occur primarily from urinary obstruction with distention of the renal capsule. The pain reaches its maximum 1–2 h after the start. In the constant phase, the period of sustained maximal pain, the pain tends to remain constant until it is either treated or allowed to improve spontaneously. Most patients arrive in the ER during this phase of the attack. In the final phase of renal colic, relief can occur spontaneously at any time after the initial onset and most commonly lasts 1.5–3 h.

The pain may localize at different sites of the abdomen depending on the exact position of the calculus in the urinary tract. Stones commonly become impacted in the urinary tract in a calyx, at the ureteropelvic junction (UPJ), at the pelvic brim where the ureter begins to arch over the iliac vessels, at the broad ligament in females, and at the ureterovesical junction, which is the most common site of impaction. Pain from upper ureteral calculi tends to radiate to the flank and lumbar areas. Mid-ureteral calculi cause pain that radiates anteriorly and caudally. Distal ureteral calculi cause pain that tends to radiate into the groin or testicle in the male or labia majora in the female. If a calculus is lodged in the distal intramural part of the ureter, symptoms may mimic detrusor overactivity or cystitis. These symptoms include suprapubic pain, urinary frequency, urgency, dysuria, or pain at the tip of the penis in men.

On examination of the abdomen, the pain localizes to the costovertebral angle. The remaining examination findings are often unremarkable. The characteristic difference between patients with renal colic and those with an acute abdomen lies in the restlessness of patients

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with renal colic. Patients with an acute abdomen of surgical origin usually lie as still as possible. Rebound tenderness will be present in an abdomen with peritonitis. The pain is generally diffuse in an acute abdomen as opposed to renal colic where the patient can often point to the site of maximum tenderness, which is likely to be the site of the ureteral obstruction.

Hematuria is often associated with renal colic. However, 15% of all patients with urinary calculi do not have hematuria [2]. Therefore, the lack of hematuria does not exclude the possibility of acute renal colic. Other clinical signs that may be encountered are fever, chills, nausea, vomiting, and tachycardia. The presence of pyuria, fever, leukocytosis, or bacteriuria suggests the possibility of a urinary infection and the potential for an infected obstructed kidney. This is a potentially life-threatening situation and should be treated as a surgical emergency.

Mechanism of renal colic

Renal colic is the consequence of the acute dilation of the urinary tract proximal to an obstruction along with smooth muscle spasm at the site of the obstruction. High intrarenal pressure promotes local synthesis and release of prostaglandin E2 with subsequent vasodilation of the afferent arterioles, which promotes diuresis and a further rise in renal–pelvic pressure, potentially exacerbating the patient's pain. In addition, ureteral smooth muscle spasm is directly stimulated by prostaglandin E2 [3]. Most of the pain receptors of the upper urinary tract responsible for the perception of renal colic are located submucosally in the renal pelvis, calyces, renal capsule, and upper ureter. Acute distention seems to be most important in the development of the pain of acute renal colic. Muscle spasm, increased proximal peristalsis, and local inflammation at the site of obstruction may contribute to the development of pain through chemoreceptor activation and stretching of submucosal free nerve endings. Renal colic pain rarely, if ever, occurs without obstruction.

Autoregulatory process associated with obstruction

The initial renal response to acute unilateral ureteral obstruction is the release of prostaglandins, especially E2, resulting in vasodilatation of the afferent arterioles and worsening of ureteral smooth muscle spasm. Subsequently, the dilation of the afferent arterioles results in an increase in renal blood flow and glomerular filtration rate [4]. As a consequence, more urine is produced, and the renal pelvis and ureter dilate further. Distention of the renal pelvis initially stimulates ureteral hyperperistalsis. Peak hydrostatic renal pelvis pressure is attained within 2–5 h after a complete obstruction. The initial phase of obstruction lasts approximately 1.5 h and is followed by vasoconstriction of the efferent arterioles with a resultant decrease in renal blood flow. Eventually, the afferent arterioles constrict and ureteral pressures fall [4]. By this time, intraureteral pressures have returned to normal, but the proximal ureteral dilation remains and ureteral peristalsis is minimal. The interstitial edema of the ipsilateral kidney enhances fluid reabsorption, which helps to increase the renal lymphatic drainage to establish a new, relatively stable, equilibrium. At the same time, renal blood flow increases in the contralateral kidney as renal function decreases in the obstructed kidney. The return of renal function after a period of complete unilateral ureteral obstruction is an important clinical concern for the urologist. The renal function recovery rate after 1 week of ureteral obstruction is 100%, but after 4 weeks only a 30% recovery can be expected [5]. If only a partial obstruction is present, the same changes occur, but to a lesser degree.

Diagnosis

The diagnosis of renal colic is often made based on clinical symptoms alone, although confirmatory tests are usually performed. Additional tests are useful not only to confirm the diagnosis but also to facilitate in the decision-making process on further treatment. Before a decision on treatment can be made, a urologist must know the size, shape, orientation, radiolucency, and location of the stone. Other factors that may influence further treatment are kidney function and the presence of infection, as well as all other clinical information and comorbid conditions the patient may have.

Laboratory investigations

Urinalysis

Patient history, physical examination, and urinalysis alone cannot help confirm or exclude urolithiasis with sufficient accuracy. In particular, hematuria testing has a sensitivity of 81–84% and a specificity and negative predictive value of 48% and 65%, respectively [6, 7].

In addition to the presence of blood in the urine, the presence or absence of leukocytes, crystals, and bacteria, and the urinary pH should be documented. A urinary tract infection should be suspected if the number of white blood cells (WBCs) in the urine is greater than 10 per high-power field. Determining urinary pH may be helpful in planning treatment. With a pH lower than 6.0, a uric acid stone should be considered. The observation of cystine, uric acid, struvite, or calcium oxalate crystals in the urine may be an indication of the type of calculus ultimately found.

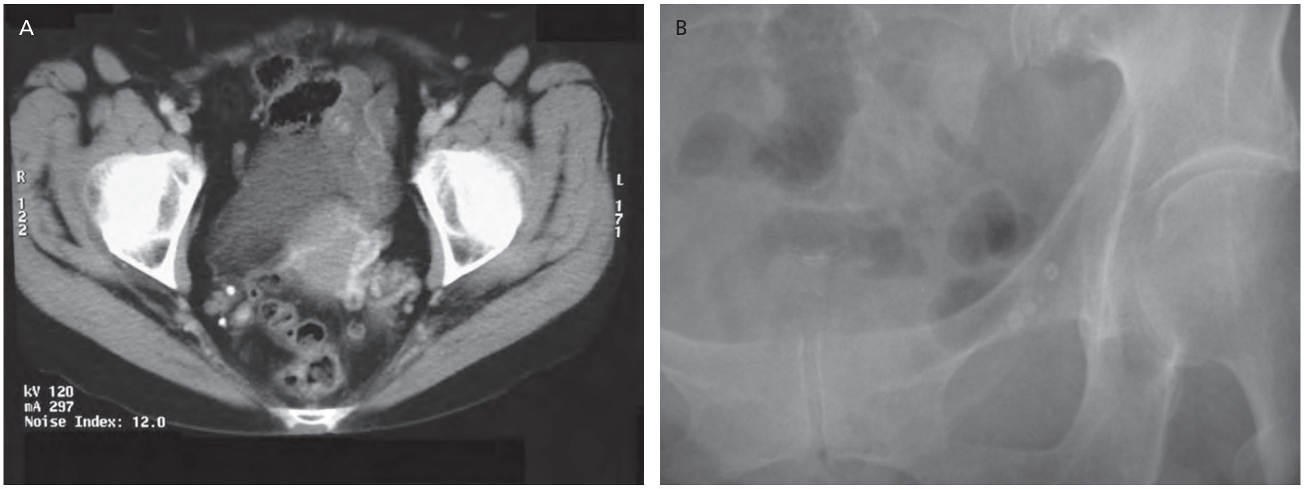

Figure 59.1 (A) Distinguishing renal calculi from phleboliths in the pelvis can be intricate. This axial noncontrast CT demonstrates two phleboliths in the pelvis. One demonstrates the comet-tail sign, which is a soft tissue attenuation leading to the phlebolith and represents the vein in which it is located. (B) On a KUB radiograph, a phlebolith classically demonstrates a central lucency whereas ureteral calculi do not.

Hematologic tests

While mild leukocytosis often accompanies a renal colic attack, a high index of suspicion for a possible infection should accompany any serum WBC count of 15 000/µL or higher in a patient presenting with an apparent acute kidney stone attack, even if afebrile. Urea, creatinine, and electrolyte testing may be helpful in identifying patients with renal function impairment as well as in giving some information on the hydration status of the patient, which may determine their further management.

Imaging studies

Plain abdominal radiograph

The historical cornerstone of the evaluation of renal colic was a radiograph of the kidneys, ureters, and bladder (KUB). Not all urinary calculi will be visible on the KUB radiograph because of their small size, calculus radiolucency, or overlying bowel gas. Typically, 90% of calculi are radio-opaque. However, many calcifications that can be observed on the KUB radiograph are not calculi, but phleboliths, vascular calcifications, calcified lymph nodes, or bowel contents. Typically the differentiation between a phlebolith and a urinary calculus becomes easier when the KUB radiograph demonstrates a lucent center, identifying the calcification as a phlebolith. However, this central lucency is not observed as often on computed tomography (CT) scans. The KUB radiograph is also quite accurate for helping determine the size and shape of a visible radio-opaque calculus. It uses the same orientation and anatomic presentation that is observed on fluoroscopy images during endoscopic ureteral surgery. Also, the progress of the stone can be easily monitored with a follow-up radiograph. For these reasons, many urologists recommend a KUB in addition to a CT scan in the work-up of renal colic (Figure 59.1).

Renal ultrasound

Renal ultrasound is most useful in diagnosing relatively large calculi within the renal pelvis or kidney. However, it is less useful than other modalities for detecting ureteral calculi. One benefit is that it can easily diagnose any significant hydronephrosis. Ultrasound can also be used to diagnose other pathologic conditions such as abdominal aortic aneurysm or cholelithiasis, which can sometimes be mistaken for acute renal colic. Combining a renal ultrasound with a KUB radiograph can be adopted as a reasonable alternative when a CT scan cannot be performed.

Intravenous urogram

Intravenous urography (IVU) has been the imaging modality of choice for investigating acute renal colic since Osborne *et al.* first described it in 1923 [8]. It provides detailed information about the anatomy of the renal collecting system and ureters, offers some information about renal function and the degree of obstruction, and is good for the planning of calculus surgery (Figure 59.2). When a patient has multiple pelvic calcifications, identifying the actual stone is simple with an IVU and it can also show nonopaque calculi as filling defects.

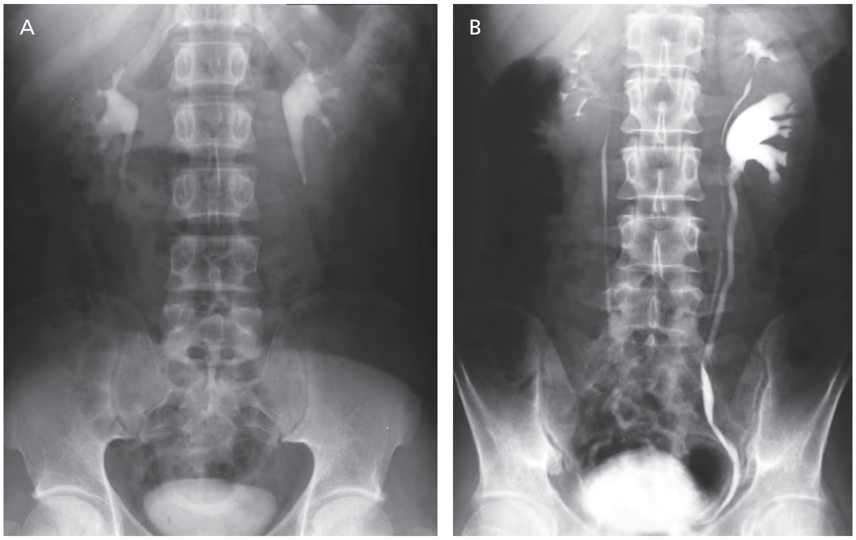

Figure 59.2 (A) An intravenous urogram (IVU) obtained in a patient with renal colic demonstrates a calculus of less than 6 mm, normal anatomy, and no signs of obstruction, which makes for the ideal candidate for medical expulsive therapy. (B) IVU image demonstrates a calculus of greater than 6 mm at the ureteropelvic junction in the lower moiety of a kidney with complete ureteral duplication. This represents a clear indication for surgical intervention.

There are, however, limitations: adequate bowel preparation is necessary for good quality studies, and there is a risk of contrast-related allergic and anaphylactic reactions (10% and 1% of patients, respectively) [9]. Also, in patients with renal failure and diabetes mellitus, the risk of contrast-induced nephrotoxicity is 25% [10]. A serum creatinine level of more than 2 mg/mL is a relative contraindication to the use of intravenous contrast. Furthermore, there may be a need for delayed films if there is high-grade obstruction, which can lead to delays in diagnosis and treatment.

The classic finding of acute ureteral obstruction is a persistent nephrogram, caused by an increase in the intrarenal concentration of the contrast. Even without observing any specific calculus, the presence of a persistent nephrogram in one kidney with prompt contrast excretion by the contralateral kidney is highly suggestive of ureteral obstruction secondary to a calculus. There may also be columnization on the delayed films. Extravasation of contrast around the collecting system may be a sign of a ruptured fornix, while pyelolymphatic backflow indicates that contrast has entered into the renal lymphatic drainage system. Both are considered signs of a more severe ureteric obstruction.

Computed tomography scan

The use of a noncontrast helical CT (NCCT) scan to assess patients with acute flank pain was first reported in 1995 by Smith *et al*. [11]. Recent studies have shown that NCCT is more accurate and reliable than IVU in making a diagnosis in patients presenting with acute flank pain. NCCT has both sensitivity and specificity of 94–100% compared with 60–94% for IVU, partly because NCCT clearly demonstrates both radio-opaque and radiolucent stones, as well as detecting alternative causes for a patient's symptoms [12, 13]. Unrelated pathology may be detected by NCCT in 28% of patients [14]. Moreover, NCCT does not require special preparation or intravenous contrast, thus avoiding the risk of contrast-associated reactions and allowing imaging studies to be completed in a few seconds, which improves image quality by reducing respiratory motion and artifact [15, 16]. For these reasons, NCCT has displaced IVU to become the investigation of choice for acute flank pain in many institutions across North America, Europe, and Australasia [13, 17, 18].

Very narrow cuts are taken through the kidneys and bladder areas, where symptomatic calculi are most likely to be encountered (Figure 59.3). A KUB radiograph is sometimes automatically included in a renal colic study, as mentioned earlier.

Katz *et al*. found that CT scan estimates of stone size to be similar to those determined by plain film radiography [19]. Both the estimated mean stone diameter and the length were similar on CT and KUB. The limitation of this method is that if CT collimation is too large relative to the stone, the entire stone may not be scanned, leading to underestimation of stone length. This inaccuracy can be best compensated for by making sure that slices are small in relation to stone size. Therefore, 5-mm collimation is preferred to 10-mm collimation. In addition to verifying similarity of stone size estimates by CT and KUB, Katz *et al.* also found that the prediction of

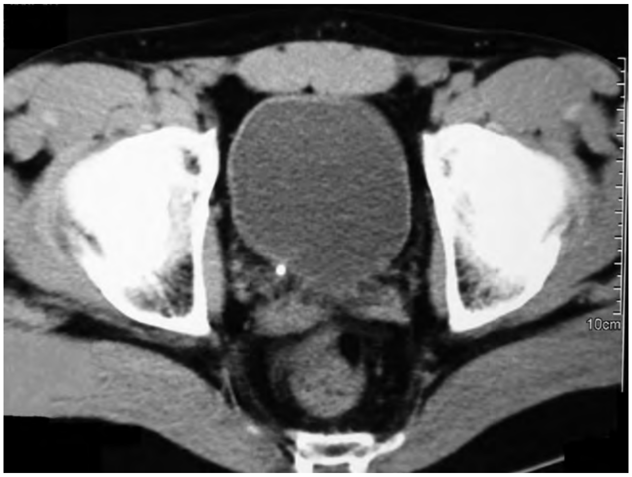

Figure 59.3 Classic example of a calculus of less than 6 mm at the ureterovesical junction. Medical expulsive therapy would be an appropriate course of action.

spontaneous stone passage was similar using the two imaging modalities. It is widely believed that transverse stone dimension is more important than length in predicting the likelihood of spontaneous passage. Interestingly, the study demonstrated the measured anteroposterior stone diameter on CT to be wider in many cases than the measured transverse diameter on CT and plain film. This result could be explained by orthogonal imaging in curved portions of the ureter, where larger anteroposterior diameters were found irrespective of stone location. At any given point along the CT scan, the ureter is either ascending or descending; therefore, an anteroposterior cut would slice tangentially, and cause a wider anteroposterior than transverse diameter.

Phleboliths are often confused with ureteral calculi. On a KUB radiograph, the characteristic lucent center of a phlebolith is often visible, but is not present in a true calculus. Unfortunately, as mentioned above, CT scans usually fail to reveal this central lucency. The "rim sign," originally reported by Smith *et al.* in 1995, is described as a rim or halo of soft tissue, visible on CT scans, that completely surrounds ureteral calculi [11]. This effect is enhanced by the local inflammation in the ureteral wall with subsequent edema at the site of the calculus. The rim sign is generally incomplete with phleboliths. The rim sign is more likely to be present in small stones up to 5 mm in diameter.

Calculi, including relatively radiolucent uric acid calculi, and cystine and matrix stones are easily identifiable on CT scan. While they do not contain calcium, they are still much denser than the surrounding soft tissue. The only exception is indinavir calculi, which are not visible on CT scans. These patients require an IVU that will demonstrate a filling defect.

Currently, CT scans can be used to estimate the relative density of the calculus and composition to some extent. The mean peak Hounsfield reading of uric acid calculi and calcium oxalate calculi are around 344 ± 152 HU and 652 ± 490 HU, respectively [20].

Secondary signs of obstruction may be visible on CT scans. In some cases, if the stone passed shortly before the study, these signs may be the only evidence that the patient had a stone. These secondary signs include ureteral dilation with hydronephrosis and renal enlargement with streaking of the perinephric fatty tissue [2]. Although NCCT is unable to provide direct information on function and drainage, the degree of obstruction can be assessed by secondary signs, such as the severity of hydronephrosis and ureteral dilation and the presence of perinephric fluid, indicating forniceal rupture. Smith *et al*. found a high correlation between secondary signs of obstruction and the presence of a ureteral calculus. In particular, the combination of collecting system dilation and perinephric stranding had a positive predictive value of 98%, while the absence of both of these secondary signs had a negative predictive value of 91% [21].

The biggest advantage of a CT scan over an IVU lies in its ability to diagnose other underlying pathology mistaken for renal colic, such as aortic aneurysms, pancreatitis, appendicitis, ovarian problems, and bowel disorders.

Disadvantages of a CT scan include difficulties in identifying a stone if the patient exhibits limited hydronephrosis with additional pelvic calcifications and the little information it gives on the renal function. Stone location can be described in anatomic terms, but the scan lacks the surgical orientation that most urologists prefer. Spiral CT scans can, however, allow for anatomic three-dimensional image reconstruction, which may be useful in the evaluation and pretreatment planning (Figure 59.4).

It is recommended to add a KUB radiograph when a renal colic CT scan study is performed for acute flank pain, especially when the CT scan findings are positive for urolithiasis. The KUB radiograph not only provides more precise information about the size and shape of a stone, but it also quickly reveals whether stones are radio-opaque or radiolucent. Follow-up evaluations are easier because only a repeat KUB radiograph is needed for comparison.

Differential diagnoses of renal colic

Alternative urologic pathology

Pyelonephritis

Pyelonephritis is a common cause of flank pain, but the discomfort is usually described as a relatively mild dull

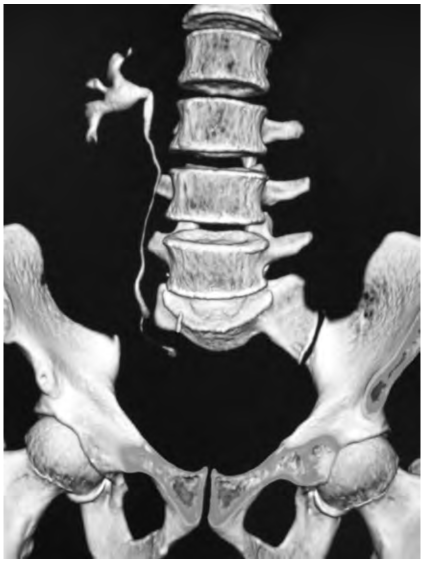

Figure 59.4 3D reconstruction of a noncontrast CT of a patient with a single kidney with a calculus impacted at the pelvic brim. This imaging option can be a valuable adjunct in high-risk patients in choosing the most appropriate treatment option as well as pretreatment planning.

ache rather than typical renal colic pain. Fever, chills, nausea, and vomiting are often associated symptoms. Flank and costovertebral angle tenderness are also present, but more severe than with renal colic.

Renal abscesses

Renal abscesses tend to cause pain similar to pyelonephritis rather than renal colic. Sometimes, a flank mass may be palpable. Urinalysis often demonstrates a urinary infection, but can be normal in some cases. Fever and chills are common. It is usually associated with patients who are immune compromised.

Kidney tumors

Kidney tumors may cause flank pain either from renal capsular stretching or by mechanical compression of large tumors. Primary tumor extension into the renal pelvis can cause urinary obstruction, although this is usually a slow process during which patients are often asymptomatic.

Ureteropelvic junction obstruction

UPJ obstruction is one of the more common causes of renal pain. The pain is similar to an acute ureteral obstruction and usually follows the intake of large amounts of fluid, which causes diuresis resulting in renal pelvic distention and colic. The pain is not as severe as renal colic and is recurrent in nature.

Obstructive uropathy due to other causes

Other obstructive causes include:
- Blood clots;
- Renal papillary necrosis;
- Ureteral strictures;
- Renal cysts;
- Polycystic kidney disease;
- Pyelocalyceal diverticulum.

Vascular pathology

Abdominal aortic aneurysms

Patients with an abdominal aortic aneurysm may present with symptoms of flank pain that mimic renal colic. Symptoms are generated from either a leaking or ruptured aneurysm. Large aneurysms may lie in close approximation to the ureter and cause hematuria from local ureteral inflammation. Abdominal aortic aneurysms are best diagnosed with ultrasound or a CT scan. CT scanning is particularly useful in cases of suspected renal colic in patients older than 50 years, who are at risk for an aortic aneurysm.

Gastrointestinal tract pathology

Causes include Crohn's disease, diverticulitis, appendicitis, cholecystitis, and pancreatitis.

Gynecologic pathology

Causes include ectopic or tubal pregnancy, endometriosis, ovarian cyst, and pelvic inflammatory disease

Medical and surgical treatment (Figure 59.5)

The management of acute renal colic is a problem commonly encountered by both urologists and emergency medicine physicians. One aspect of the medical treatment is the management of acute renal colic pain, a condition that demands rapid and effective analgesia. Currently, nonsteroidal anti-inflammatory drugs (NSAIDs) and opioids are the best agents for acute renal colic, overshadowing other drugs such as antimuscarinics (i.e. hyoscine butylbromide) [22].

In addition to controlling the pain associated with obstructing calculi, drug therapy that promotes the expulsion of stones is an evolving aspect of medical therapy.

Observation with analgesia is most appropriate for patients without infection whose pain can be well-controlled with oral medications. Key factors contributing to stone retention include edema, ureteral spasm, and infection, all of which are potential pharmacologic

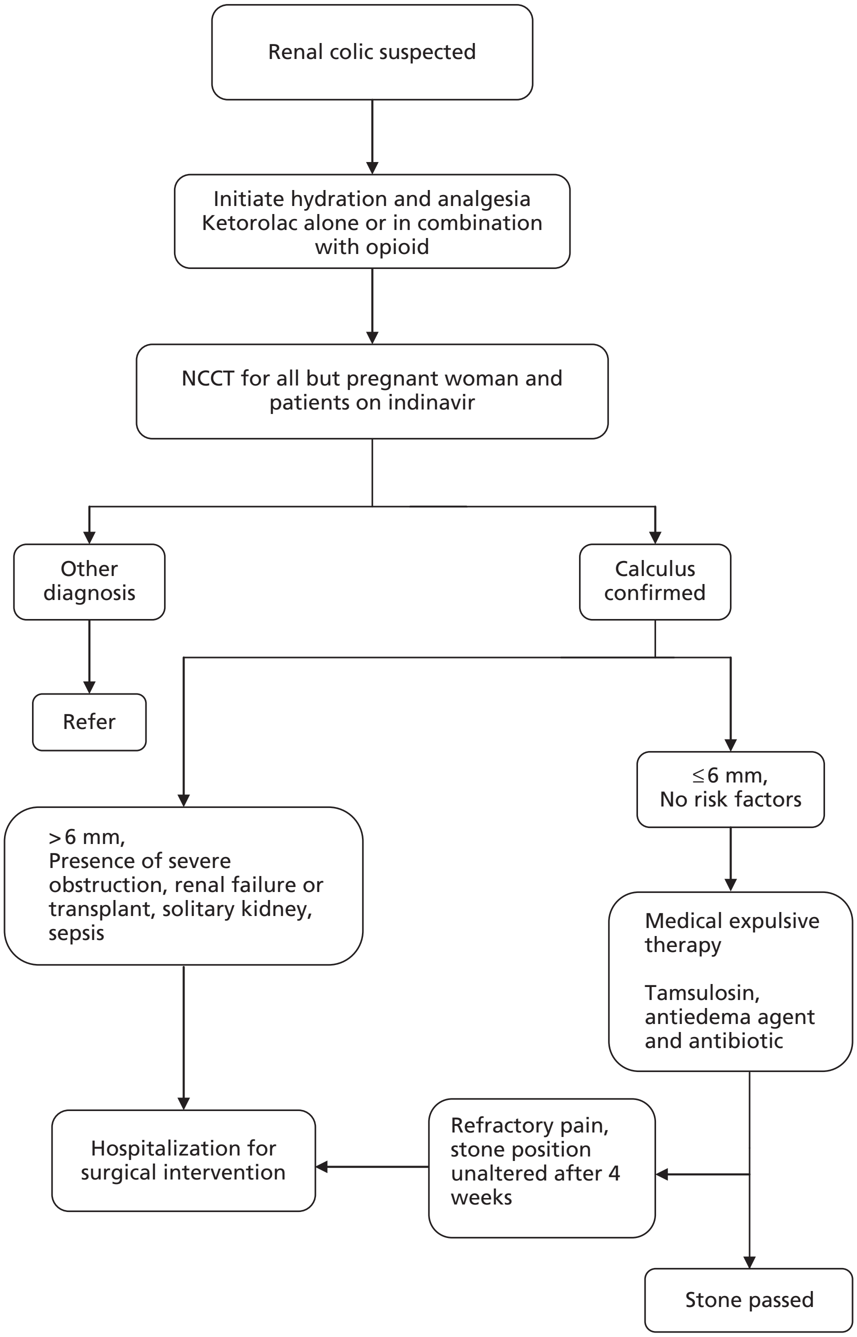
Renal colic suspected
Initiate hydration and analgesia Ketorolac alone or in combination with opioid
NCCT for all but pregnant woman and patients on indinavir
Other diagnosis
Calculus confirmed
Refer
≤6 mm, No risk factors
>6 mm, Presence of severe obstruction, renal failure or transplant, solitary kidney, sepsis
Medical expulsive therapy
Tamsulosin, antiedema agent and antibiotic
Hospitalization for surgical intervention
Refractory pain, stone position unaltered after 4 weeks
Stone passed

Figure 59.5 Algorithm depicting the course of evaluation, triage, and further management of a patient with suspected renal colic. NCCT, noncontrast CT.

targets. However, in cases of persistence, ureteral obstruction, or pain, other minimally invasive interventions are preferred [23].

Triage

The majority of ERs in the USA (87.4%) do not have guidelines regarding the treatment of patients who present with renal colic [1]. Having well-designed guidelines in the ER will not only facilitate and expedite diagnosis and enable appropriate treatment, but will also significantly decrease patient morbidity and channel patients with life-threatening conditions to the appropriate departments without delay. Such guidelines should help acquire the most suitable imaging modalities, decide which patients should be hospitalized or referred to other departments, and facilitate in the triage and decision-making on conservative versus surgical therapy.

Predicting spontaneous stone passage

Setting patient expectations with regard to the likelihood of spontaneous stone passage and the time to stone passage is critical to help guide the patient to make an informed decision between conservative management and surgical intervention. The management of patients with ureteral calculi relies on estimated stone size and the stone's potential for spontaneous passage. Several factors influence the likelihood of spontaneous stone passage, such as location and history of spontaneous expulsion. Indeed, with accurate information, more patients might select early intervention as opposed to expectant observation. In general, smaller calculi are more likely to pass spontaneously, but stone passage also depends on the specific anatomy of the upper urinary tract. Any anatomic abnormality could make the passing of even a small stone impossible.

Spontaneous passage of urinary calculi of less than 5 mm in diameter may occur in most patients, although the calculus may take 40 days or more to pass [24]. Prospective clinical trials have stratified the spontaneous stone passage rate and time to stone passage. Stones of 4 mm and smaller have a 94% chance of spontaneous passage, whereas stones of 4–6 mm in size will pass spontaneously 50% of the time. Average time to stone passage was 1 week for a stone of less than 2 mm, 2 weeks for a stone of 2–4 mm, and 3 weeks for a stone of 4–6 mm. Calculi of greater than 6 mm are unlikely to pass spontaneously [25–28].

Excluding complications related to stone disease, such as severe hydronephrosis, renal insufficiency, intractable pain, and infection, that mandate a more aggressive approach (ureteral stent, nephrostomy, retrograde intrarenal surgery, extracorporeal shock-wave lithotripsy), drug therapy is useful in the management of urolithiasis and represents an important adjunct to conservative therapy.

With regard to cost, observation represents the most cost-effective approach to ureteral calculi, but it remains unsatisfactory for recurrent stone formers, in whom the high rate of recurrence precludes a conservative approach [29]. A cost-effectiveness model revealed that a conservative approach to ureteral stones is associated with lower cost than any invasive procedures only if it is followed by stone expulsion [30].

It is suggested that a conservative approach to larger ureteral stones should not be extended for longer than 2 weeks in order to avoid renal function impairment, urosepsis, and intractable pain [31]. Many urologists have adopted the conservative treatment plan of 4 weeks proposed by Hubner *et al*. [28]. This is safe if the stone is 6 mm or smaller in the absence of severe hydronephrosis.

Hospitalization

The decision to hospitalize a patient with a stone is usually made based on clinical grounds rather than on any specific finding on a radiograph. Watchful waiting for spontaneous stone passage is certainly the least invasive management option; however, several signs and symptoms may prohibit such a course of action. Fever, chills, or other sign of infection are the most urgent scenarios prohibiting watchful waiting. Evidence of renal insufficiency or frank anuria similarly necessitates urgent intervention. Poorly controlled renal colic pain and vomiting are more subjective indications. Other than extreme cases necessitating inpatient management, clinical scenarios that may warrant acute intervention include inability to perform routine activities safely and reliably, upcoming travel plans, job restrictions, etc. [32]. Patients with obstructing ureteric stones of greater than 6 mm are seldom likely to pass their stone spontaneously, and early admission for procedural therapy may be prudent [2]. Most patients with acute renal colic can be treated on an ambulatory basis. Hospitalization for an acute renal colic attack rarely lasts for longer than 24 h, after which the patient can go home.

Surgical intervention

The presence of urosepsis in a patient with an obstruction from stone disease is a true surgical emergency. This condition requires hospital admission with intravenous fluids, antibiotics, and most importantly, early drainage of the affected kidney using either retrograde placed double-J stents or percutaneous nephrostomy.

Retrograde endoscopy should be reserved for relatively mild cases that are medically stable. Double-J stents virtually guarantee drainage of urine from the kidney and bypass the obstruction. This relieves patients of their renal colic pain even if the actual stone remains.

In patients with pyonephrosis in association with an obstructing calculus, retrograde endourologic procedures, such as retrograde pyelograms and double-J stent placement, may worsen the infection by pushing infected urinary material into the obstructed kidney and may exacerbate the systemic sepsis. These situations clearly indicate the need for a percutaneous nephrostomy, especially in patients who are hemodynamically unstable. Later, when the infection is under control and the patient is no longer septic, a more definitive procedure can be performed to remove or fragment the obstructing stone.

Approximately 10–20% of all kidney stones may cause the patient enough problems to require surgical removal. If there is no evidence of movement or passage of a ureteral stone that has been treated conservatively for 3–4 weeks or if pain is intractable, surgical intervention is warranted. Other conditions that may require a more expedited approach are the presence of unusually large stones, high-risk medical conditions, uncontrollable pain, renal failure, solitary kidneys, renal transplants, and pregnancy.

Hydration

Initial treatment of a renal colic patient in the ER starts with obtaining intravenous access to allow fluid, analgesic, and antiemetic medications to be administered. Some patients may be dehydrated from nausea and vomiting. Some believe hydration may increase the speed of passage of a stone through the urinary tract. Traditionally, patients were aggressively hydrated intravenously or were told to increase their oral hydration in order to promote stone passage [33]. This practice stems from the thought that the stone might pass spontaneously if forced hydration is utilized. Using hydration as a therapy to assist stone passage remains controversial.

Some urologists worry that the extra fluid only increases the hydrostatic fluid pressure inside the blocked renal unit, exacerbating the pain. In addition to this, diuresis may be detrimental to the ipsilateral renal unit by potentially causing forniceal rupture [34, 35]. Therefore, fluid restriction may be more advantageous to the patient.

Maintenance intravenous fluids are as efficacious as forced hydration with regard to patient pain perception and narcotic use. Moreover, it appears the state of hydration has little impact on stone passage [36].

Intravenous hydration during an episode of renal colic is necessary in patients who are unable to tolerate liquids by mouth. It is therefore recommended that patients who have been vomiting or have laboratory values suggesting dehydration receive appropriate replacement fluids plus their normal maintenance requirements.

Pain relief

The two principal classes of drugs used for analgesia in renal colic are NSAIDs and opioids. The combination of these drugs is currently the preferred treatment of renal colic at most emergency departments.

Narcotics and opioids

The mainstay of medical therapy for patients with acute renal colic is parenteral narcotic analgesics. These medications work primarily on the central nervous system (CNS) to reduce the perception of pain. When considering a medication and dosage range, it must be remembered that acute renal colic is probably the most painful episode to affect humans. Morphine, meperidine, and tramadol are the most commonly used drugs.

Morphine is the principal opium alkaloid product. As a potent narcotic analgesic, morphine sulfate controls severe pain primarily through a CNS mechanism. Adverse effects include respiratory depression, drowsiness, nausea, and vomiting. The usual dose of morphine sulfate is 10 mg/70 kg of body weight intramuscularly every 4 h. For more rapid results, morphine sulfate can be administered intravenously in doses of 4–10 mg, but it must be administered slowly to avoid excessive adverse effects and respiratory depression.

Similar to morphine sulfate, meperidine is a potent parenteral narcotic analgesic. Doses of 1 mg/kg should be adequate to bring relief to a patient with renal colic. Meperidine offers a slightly more rapid onset of action and slightly shorter duration of analgesic activity than morphine sulfate. The dosage range is usually 1 mg/kg intramuscularly every 4 h. This dosage is reduced by at least 50% when administered intravenously. The actual effective dosage varies according to the source of the pain and the individual's tolerance. As with morphine sulfate, intravenous administration should be performed slowly.

Tramadol is a synthetic cyclohexanol derivative used since the late 1970s. It is a centrally-acting analgesic with inhibition of serotonin and norepinephrine reuptake. Fewer side effects are seen with tramadol, although it is less effective for severe pain [37]. Negligible cardiac and respiratory depression has been shown, and reported side effects are minor: mainly nausea and emesis, usually preventable by slow injection of the drug and prophylactic administration of an antiemetic.

For long-lasting pain relief, intravenous opioids titrated to effect are recommended. However, on-demand intravenous titration of drugs is difficult to organize in a busy emergency department, especially if patients have to leave for the medical imaging department. A continuous intravenous tramadol drip, on the other hand, proved to offer superior analgesia and greater patient satisfaction without an increase in reported side effects [37].

Nonsteroidal anti-inflammatory drug therapy

NSAIDs have a direct action on the underlying cause of the pain by inhibiting prostaglandin synthesis, and subsequently reduce vasodilatation with a drop in intrarenal pressure, inhibit ureteral smooth muscle contraction, and reduce urinary tract inflammation [38].

There are various NSAIDs available for either intramuscular or intravenous use. The most common intravenous NSAID used in the USA is ketorolac, which works at the peripheral site of pain production rather than on the CNS. It has fewer adverse effects and often provides dramatic improvement in pain symptoms. The dosage is an initial 30–60 mg intramuscularly or 30 mg intravenously, followed by 30 mg intravenously or intramuscularly every 6–8 h. Ketorolac has been shown to be as effective in the treatment of renal colic as the narcotic meperidine [39, 40].

In more severe cases, ketorolac can be combined with narcotic analgesia with better analgesic effect than either one administered individually. Once the acute episode has been dealt with, an oral NSAID can be used. Of the various enteral NSAIDs, ketorolac, ibuprofen or the newer oral cyclo-oxygenase-2 inhibitors are equally effective for pain management in outpatients. Chemically, ketorolac and ibuprofen are similar to Aspirin and may increase the prothrombin time when administered with anticoagulants. They should be avoided in patients with peptic ulcer disease, renal failure, or recent gastrointestinal bleeding.

Antidiuretics

Desmopressin (DDAVP), a potent antidiuretic medication that is essentially an antidiuretic hormone, can dramatically reduce the pain of acute renal colic in many patients. It is thought to work by reducing the intraureteral pressure, but it may also have some direct relaxing effect on the ureteral musculature. Whether this therapy significantly affects eventual stone passage is unknown [41].

It is available as a nasal spray (usual dose of 40 μg) and as an intravenous injection (4 μg/mL). Generally, only one dose is administered.

While some of the human studies lack adequate controls and further studies must be conducted, desmopressin therapy currently appears to be a promising alternative to analgesic medications in patients in whom narcotics cannot be used or in whom the pain is unusually resistant to standard medical treatment.

Antiemetics

Because nausea and vomiting frequently accompany acute renal colic, antiemetics often play a role in renal colic therapy. Metoclopramide is a well-known agent in the treatment of renal colic. Its antiemetic effect stems from its dopaminergic receptor blockage in the CNS. The effect after intravenous injection of 10 mg is rapid; within 3 min the patient experiences relief. Other medications commonly used as antiemetics include promethazine and prochlorperazine. Anti-emetics are recommended when patients with renal colic have been vomiting actively or report nausea sufficient to interfere with oral therapy.

Medical expulsive therapy

As discussed above, stone size affects expulsion times, but other factors such as stone shape and edema around the stone may also have an effect. Additionally, the sympathetic nervous system modulates ureteral activity, as demonstrated by the presence of adrenergic receptors in the ureter. Various medications or combinations thereof have been used to facilitate and expedite the passage of ureteral stones. The rationale for the combination of an anti-inflammatory drug (NSAID or steroid) with a smooth muscle relaxant (nifedipine or tamsulosin) is that the former will reduce edema while the latter will inhibit stone-induced ureteral spasm, thus maintaining peristaltic rhythm [30, 42, 43].

However, medical expulsive therapy (MET) should only be used in favorable conditions for spontaneous stone passage. Patients who elect for MET should have well-controlled pain, no clinical evidence of sepsis, and adequate renal functional reserve. Patients should be followed with periodic imaging studies to monitor stone position and to assess for hydronephrosis. Since patient complaints and stone size do not predict future renal function loss and time to permanent renal injury cannot be easily estimated, intervention should be recommended for any patient with persistent obstruction, failure of stone progression, or recurrent colic pain.

Alpha-adrenergic antagonists

The presence of alpha- and beta-adrenergic receptors have been demonstrated in human ureters. α1-Adrenergic receptors, particularly subtype α1d, are present in high density in the lower ureteral segment and may play an important role in lower ureteral physiology [44]. Norepinephrine is the main alpha-agonist and exerts a positive chronotropic and inotropic effect on the ureter. As a result, stimulation of alpha-adrenergic receptors decreases the volume of urine flow through the ureter.

Alpha-adrenergic antagonists are able to inhibit the basal tone and peristaltic frequency, dilating the ureteral lumen and facilitating in stone passage [45]. Several investigators have shown the utility of α1-blockers and their spasmolytic action in the active expulsion from the distal ureter [31, 46]. Tamsulosin may increase the urine bolus, and thus the pressure, above the stone; at the same time, the agent may decrease peristalsis, and thus the intraureteral pressure, below the stone. The net effect is an increased intraureteral pressure gradient around the stone, which ultimately results in a stronger expulsive force [35].

Yilmaz *et al*. evaluated tamsulosin, terazosin, and doxazosin alone compared with watchful waiting and found a significant increase in spontaneous stone passage with all three alpha-blockers (79%, 78%, 76%, and 53%, respectively) [47]. A recent meta-analysis of 11 randomized clinical trials in more than 900 patients concluded that alpha-blockers increase the rate of spontaneous stone passage by 44% [48].

Moreover, α1-blockers reduce the need for analgesia by decreasing the frequency of peristaltic contractions in the obstructed ureteral tract, thus decreasing the frequency of ureteral colic [49]. There may be a double action of tamsulosin on the control of pain associated with ureteral colic; one on the smooth muscle, preventing spasm, and a second on C-fibers or sympathetic postganglionic neurons, which also block pain conduction to the CNS [50]. In addition, tamsulosin drastically decreases the need for hospitalization (10% vs 27.5%), as well as the need for endoscopic procedures (0 vs 13%) [31].

Calcium channel blockers

The primary functional anatomic unit of the ureter is the smooth muscle cell, which functions in response to changes in calcium ion concentration. At the most fundamental level, an increase in calcium concentration results in relaxation. Ureteral stones induce ureteral spasm, which results in arrest of stone passage. Studies in both animal and human ureters show that calcium antagonists, namely nifedipine, inhibit the quick phasic contractions without affecting tonic activity [42]. Calcium channel blockers such as nifedipine represent a valid and well-established pharmacologic treatment for urolithiasis owing to their spasmolytic action on the ureter.

Porpiglia *et al.* showed that medical treatment with nifedipine and deflazacort was both safe and effective, as evidenced by increased stone expulsion rate, decreased expulsion time, and reduced need for analgesic therapy [42]. Borghi *et al.* may have provided the most compelling evidence for the isolated effect of nifedipine when they compared nifedipine plus methylprednisolone with prednisolone alone in ureteral stones of up to 15 mm, and reported a success rate of 87% in the nifedipine arm compared with 65% in the control arm [51].

Two studies have compared alpha-blockade with calcium channel blockade with regard to spontaneous stone passage, with both finding an advantage for tamsulosin. Dellabella *et al.* evaluated patients with ureteral stones of greater than 4 mm and found tamsulosin to be the most effective, with a 97% success rate and an average of 72 h to passage compared with 77% for nifedipine, with an average of 120 h to passage [50]. Porpiglia *et al.* compared tamsulosin plus deflazacort with nifedipine plus deflazacort in a control group. Although not as significant as the findings in the study by Dellabella *et al.*, there was a slight advantage of tamsulosin over nifedipine for overall effect (85% vs 80%) and days to passage (7.7 days vs 9.3 days) [52].

Nifedipine blocks all ureteral contraction, while tamsulosin significantly reduces it, but still maintains some baseline activity. Thus, both agents work well to block the disorganized counteractive contractile activity associated with ureteral spasm, but the possibility of maintaining some degree of antegrade peristalsis allowed by alpha-blockade may explain the slight advantage [32]. Therefore, it is advocated to use tamsulosin as a first-line approach for the outpatient management of patients with distal ureteral stones.

Combination therapy

Based on data that suggest a higher rate of spontaneous stone passage, fewer days lost from work, and fewer surgical procedures, some urologists advocate a more aggressive medical approach. This treatment plan is intended for short-term use only but may benefit selected patients who can take medications reliably. A combination of drugs can be used together to improve the chances of spontaneous stone passage and alleviate renal colic discomfort.

Typically used combination therapy to facilitate spontaneous expulsion of urinary calculi consists of:

- Ketorolac or similar NSAID for 5 days;
- Tamsulosin or nifedipine for 7 days;
- Levofloxacin or trimethoprim/sulfamethoxazole for 7 days;
- An oral opioid pain medication as needed for breakthrough pain;
- Metoclopramide or prochlorperazine as needed for control of nausea.

Most ER physicians (76%) use ketorolac for pain management in renal colic, either alone (42.3%) or in combination with morphine (33.7%) [1]. A double-blind, randomized controlled trial demonstrated that the combination of intravenous ketorolac and morphine was superior at reducing pain scores and the need for rescue morphine compared with single-agent therapy [53].

Combination therapy may also increase the efficacy of expulsive therapy. Both ureteral spasm and edema play a role in preventing stone passage. In this regard, the combination of nifedipine (an antispasmodic) and a corticosteroid (antiedema agent) is recognized to be well-tolerated and effective in promoting ureteral stone passage [30].

Because it is widely recognized that infection within the ureter is a possible cause of calculus retention, it seems advisable to include an antibiotic in the standard approach to the patient with a symptomatic ureteral stone. One week of levofloxacin 250 mg could be an appropriate and reasonable measure in this setting [31].

Straining the urine

Stone analysis is extremely important in the evaluation of a patient with urolithiasis for stone preventive therapy. Knowing when a calculus is going to pass is impossible, regardless of its size or location. Therefore, straining of the urine of patients on MET should be continued until the stone actually is collected.

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CHAPTER 60

Anesthesia for the Endourologic Management of Stone Disease

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Percutaneous nephrolithotomy

Percutaneous nephrolithotomy (PCNL) is a less invasive alternative for urologists to remove large renal calculi in place of open surgical nephrotomy. The advantages of PCNL have been well documented and include shorter operative time, a quicker recovery period, and less postoperative pain when compared to an open procedure. It is an attractive choice for renal stones that are not amenable to other removal techniques, such as extracorporeal shock-wave lithotripsy (ESWL).

The essential components of PCNL involve a combination of technologies (e.g. ultrasound and fluoroscopic imaging, nephroscopes, and lithotripters), which are used to percutaneously access the renal pelvis so that large stones can be accessed, disrupted, and removed. Other renal disease states, from renal masses to ureteropelvic strictures, can additionally be addressed using the same underlying techniques [1]. The following discussion will focus on PCNL, as it is one of the more challenging endourology cases that anesthesiologists encounter and also encompasses the considerations for a variety of procedures involving percutaneous procedures of the kidney.

Anesthetic considerations

The patient who presents to the operating room for PCNL has been determined by the urologist to have a renal stone that is not amenable to ESWL. The choice of PCNL over ESWL can be dictated by the large size of the stone (i.e. staghorn calculus) or because the location of the stone in the kidney does not make it accessible for shock-wave therapy. Another factor pertains to the obese patient, whose body habitus is such that the distance from the skin to the kidney makes ESWL ineffective. The prospective PCNL patient will often present with some combination of both of these issues, which can confound the anesthetic plan even further.

Staghorn calculi are, by definition, large stones that involve at least two calyces. Their removal is a labor-intensive task for the urologist using percutaneous access to break up the stone and remove the pieces, occasionally requiring more than one tract to access the entire stone [2]. Larger stones generally require longer operating time with concomitant blood loss. The surgeon, in conjunction with the anesthesiologist, may choose to perform the procedure in "stages" in cases of calculi whose extraction are anticipated to be particularly difficult. This allows the patient to recover and stabilize rather than exposing them to one prolonged surgical stress.

The prevalence of obesity, morbid or otherwise, is increasingly common in the current patient population. Today's anesthesiologist is acutely aware of the increased morbidity and mortality for obese patients undergoing surgical procedures as well as the coexisting disease states that obesity often heralds. It is common knowledge that obese patients are at higher risk for diseases such as coronary artery disease, hypertension, and diabetes. Obese patients are high risk from an anesthetic standpoint because obesity adversely affects all organ systems (Table 60.1) [3].

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Table 60.1 Disorders associated with obesity [1].

Insulin resistance/ hyperinsulinemia	Asthma
Type 2 diabetes	Sleep apnea
Hypertension	Breathing difficulties
Dyslipidemia	Complications of pregnancy
Gallbladder disease	Menstrual irregularities
Cancer (prostate, endometria, uterine, cervical, ovarian, colon, kidney, gallbladder, and postmenopausal breast)	Hirsutism
Premature death	Increased surgical risk
Osteoarthritis	Psychologic distress
Stroke	

It is important to note that although obesity has an impact on the perioperative risk factors, patients undergoing PCNL have similar outcomes, regardless of their body mass index (BMI) [4].

Preoperative evaluation

The preanesthetic evaluation begins with the history and physical examination. PCNL should be considered a "moderate-to-high impact" surgical procedure because of both the location and potential for significant blood loss. All of the prospective patient's disease states should be identified and treated to ensure that the patient is "medically optimized" prior to surgery. Diabetic patients should have their blood sugar under adequate control. Patients with cardiovascular disease should have their blood pressure medically optimized and undergo preoperative studies assessing cardiac function and risk to prevent morbidity from cardiac ischemia.

Obese (BMI > 30 kg/m^2) patients are of special interest in the preanesthetic evaluation for PCNL because they have a higher incidence of renal calculi as well as obstructive sleep apnea (OSA) than the general population [5]. A yes/no format questionnaire such as STOP (Table 60.2) can assist in screening patients suspected of having OSA [6]. Two or more "yes" responses from the patient indicate a high likelihood of OSA, warranting that sleep studies be performed as part of the medical clearance. If a sleep study has not been performed in a patient who has a high likelihood of sleep apnea, extra monitoring as part of OSA precautions should be used in the perioperative period.

Anesthetic choice and perioperative monitoring

General endotracheal anesthesia (GETA) is the mainstay anesthetic technique for patients undergoing PCNL. The anesthesiologist needs to give special consideration to the potentially difficult airway in the obese patient with or without OSA [7], necessitating the use of special equipment (e.g. fiberoptic bronchoscope or glide scope) or extra personnel when inducing GETA. GETA allows the anesthesiologist to secure the patient's airway under controlled conditions prior to the patient being positioned in the prone position (most common) for the procedure. Due to the fact that the kidneys normally move with the respiratory cycle, the anesthesiologist's ability to control tidal volume and respiratory rate under GETA can improve the urologist's ability to successfully access the renal pelvis in PCNL [8].

Table 60.2 STOP questionnaire.

1. **S**noring. Do you snore loudly (louder than talking or loud enough to be heard through closed doors)?
2. **T**ired. Do you often feel tired, fatigued, or sleepy during daytime?
3. **O**bserved. Has anyone observed you stop breathing during your sleep?
4. Blood **p**ressure. Do you have or are you being treated for high blood pressure?

Although there is increasing interest in the use of a laryngeal mask airway (LMA) for patients undergoing procedures in the prone position [9], the anesthesiologist should be extremely selective and cautious when considering its use in PCNL. Having the patient intubated with muscle relaxation allows the anesthesiologist to control the patient's ventilatory parameters, compensating for metabolic acid–base derangements, which may occur during the procedure. More importantly, endotracheal intubation offers a measure of protection from aspiration that an LMA cannot in cases of high-risk [e.g. obese, history of gastroesophageal reflux disease (GERD)] anesthetized patients.

Pain sensation for the kidney and ureter correspond to the T8–L2 sensory dermatomes and, as such, are amenable to neuraxial blockade (spinal or epidural blockade). Spinal anesthesia for PCNL has been shown to be an effective alternative to GETA when a low dose of hyperbaric bupivacaine is administered in the lateral position to achieve a unilateral block with negligible hemodynamic side effects [10, 11]. The epidural component of a combined spinal–epidural technique allows the practitioner to adjust the anesthetic level and maintain it for longer periods, resulting in decreased postoperative pain when compared to general anesthesia alone [12]. Low-dose intrathecal/epidural opiates can be used in the neuraxial space to improve patient satisfaction [10–13]. While neuraxial anesthesia is an attractive alternative to GETA, routine usage should be tempered by other patient considerations, such as the anticipated duration and difficulty of the PCNL. GETA should be chosen for the safety and control of a secured airway in cases where large blood loss and hemodynamic changes with aggressive fluid resuscitation are anticipated.

The use and safety of preoperative medication to provide pre-emptive analgesia should be considered as an adjunct to improve patient satisfaction with postoperative pain management. Nonsteroidal anti-inflammatory drugs (NSAIDs) and selective cyclo-oxygenase inhibitors have been shown to decrease postoperative narcotic consumption in a wide variety of procedures [13]. The combined use of paracetamol, parecoxib, epidural lidocaine/morphine, and local anesthetic infiltration has been shown to be effective for PCNL with minimal postoperative pain [14]. Indeed, the use of 0.25% bupivacaine in the peritubal tract from the kidney to incision alleviated postoperative pain in PCNL performed under general anesthesia [15, 16], as well as improved ventilatory function in the immediate postoperative period [17].

Choice of agents in general anesthesia

A balanced technique is commonly used for patients undergoing PCNL under general anesthesia. The elements of a balanced maintenance anesthetic are a potent inhalation agent (e.g. isoflurane, sevoflurane), muscle relaxant (e.g. rocuronium, cisatracurium), and intravenous narcotics (e.g. fentanyl, morphine). Nitrous oxide should be utilized with caution as it can cause bowel distention, which theoretically increases the chance of injury during PCNL. Morphine undergoes hepatic metabolism and one of its metabolites, morphine-6-glucuronide (10%), is more potent than morphine itself. Morphine-6-glucuronide (10%) can prolong the clinical effect of morphine when administered to a patient with severe renal dysfunction [glomerular filtration rate (GFR) < 50)], necessitating dose reduction or use of another narcotic in these patients. Long-acting muscle relaxants such as pancuronium similarly undergo renal elimination and should be used with caution in patients with severe renal dysfunction.

Propofol is a short-acting sedative/hypnotic medication commonly used for induction of general anesthesia and sedation. Propofol is also included in most regimens of total intravenous anesthesia (TIVA), where general anesthesia is maintained without the aid of a potent inhalational agent. In comparison to isoflurane, propofol can lead to a significant reduction in cardiac index when patients are turned from the supine to prone position [18]. This decrease in cardiac index can result in higher than expected propofol levels, increasing the possibility of overdose in the prone position [19]. Among patients undergoing PCNL, those receiving sevoflurane had higher serum concentrations of renin, aldosterone, and adrenocorticotrophic hormone than patients receiving TIVA with propofol and alfentanyl [20].

Dexmedetomidine is an alpha-2 adrenergic receptor antagonist, which has sedative, anxiolytic, and analgesic properties with minimal respiratory depression. It has a wide variety of applications as a sedative and adjunct for general anesthesia, and its favorable respiratory profile also makes it a good candidate for use in the obese population. Dexmedetomidine can be safely used in patients with severe renal impairment [21]. Hypotension with administration should be considered in patients with borderline cardiac function.

The routine use of intra-arterial pressure monitoring (a-line) in addition to use of standard monitors (electrocardiogram, pulse oximetry, noninvasive blood pressure, gas monitors) is a reasonable consideration for the anesthesiologist. The use of an arterial line allows for realtime assessment of the patient's blood pressure and ready access to blood samples, making information about the patient's electrolytes, acid–base balance, oxygenation, and blood volume obtainable at multiple points throughout the PCNL. The addition of a central venous pressure line (CVP) can help with rapid intravenous volume resuscitation as well as a monitor of the patient's volume status. All invasive lines should be secured prior to placing the patient in the prone position in anticipation of the PCNL.

Positioning

PCNL is typically performed with the patient in the prone position to provide access to the kidneys. Chest rolls are used to support the patient and flatten lumbar spine lordosis, thus facilitating access to the kidney by the surgeon [1]. When positioning the patient prior to the procedure, the surgical team (i.e. anesthesia provider, surgeon, and circulating nurse) should take care to avoid direct pressure on peripheral nerves (e.g. ulnar nerve at the elbow) and arms should be positioned less than 90° at the shoulder to prevent stretch of the brachial plexus. Ocular injury is an exceedingly rare but devastating injury. It can occur when direct pressure is placed on the orbit or can alternatively be due to decreased venous return from the head associated with prone positioning [22]. Coexisting conditions such as diabetes, peripheral vascular disease, hypertension, and anemia (chronic or as a byproduct of surgery) can also contribute to the risk of perioperative visual loss [23].

To limit the possibility of cervical spine injury, the anesthesiologist should take special care when positioning the patient in the prone position to ensure that the neck is maintained in the neutral position, especially in patients with known disc disease. An additional consequence of moving the patient from the supine to prone position is the possibility of flexion and extension of the neck, as well as rotation of the head, which can cause migration of the tip of the endotracheal tube (ETT) within the trachea [24]. The position of the ETT should be confirmed by the anesthesiologist to ensure that is has not shifted once the prone position is achieved. If there is any question as to the position of the ETT, the placement can be assessed via fluoroscopy since it is readily available as part of the equipment required for PCNL [25].

The physiology of the anesthetized patient in the prone position shows an improvement in pulmonary function, notably in functional residual capacity (FRC), lung compliance, and oxygenation in obese and non-obese patients, in comparison to the supine position [26]. Slight decreases in cardiac index are noted with renal blood flow being preserved [27]. The increased external pressure on the abdomen compresses the abdominal contents, causing increased venous pressure. Patients in the prone position have decreased venous return from the head, which can lead to facial and airway edema. This is time- and pressure-dependant, exacerbated by the degree of fluid resuscitation required during the procedure

Although the majority of PCNL procedures are performed with the patient in the prone position, it has also been successfully carried out with patients in the lateral decubitus and supine positions, using both regional and general anesthetic techniques. The lateral decubitus position combined with neuraxial anesthesia allows the obese patient's abdominal pressure to be displaced laterally, which helps ventilatory function in a patient who is breathing spontaneously [28]. Though supine positioning for PCNL has the advantage of not requiring the repositioning of obese patients, it is generally associated with longer operative times, similar bleeding rates, and worse stone-free rates than prone PCNL [29].

Blood loss and urine output monitoring

With regard to fluid management, the operating field for PCNL is a black box from the anesthesiologist's point of view, thereby emphasizing the need for invasive monitoring. For most other surgical procedures, the anesthesiologist will monitor the blood and urine output to guide volume resuscitation of the patient. The anesthesiologist can take note of the amount of blood lost on the field or in the suction canister and measure urine output via a Foley catheter. In PCNL, however, it is almost impossible to objectively assess blood loss and urine output. The surgical field is small, consisting of a sheath that gives the surgeon partial visualization of a portion of the renal pelvis. The surgeon also uses copious amounts of irrigant to help with visualization of the renal pelvis by washing away blood and debris. The consequence of irrigation during PCNL is that blood loss and urine output are also washed from the surgical field and can therefore not be measured in any objective manner.

The vast majority of PCNL uses isotonic saline as the irrigant to avoid the electrolyte disturbances, namely hyponatremia, which are seen in post-transurethral resection of the prostate (TURP) syndrome where hypotonic solutions are utilized for visualization. Most of the irrigant in PCNL washes out of the surgical field and out of the patient. Fluid can, however, extravasate into the retroperitoneal space, resulting in delayed absorption and possible infection secondary to contamination from bacteria-laden calculus [30]. Fluid can also be directly absorbed through surgical disruption of veins, which, though typically not clinically significant, may result in fluid overload in patients with cardiopulmonary disease, renal insufficiency, and in the pediatric population, mandating extra caution in these patient populations [31].

Fluid resuscitation

For the anesthesiologist caring for a patient undergoing PCNL, the inclusion of an arterial line and/or CVP monitors allows for a measure of safety. There should always be blood products available for a PCNL due to the constantly present risk of bleeding. The anesthesia practitioner should also be aware that irrigant can be passively absorbed into the venous system, thereby increasing intravascular volume.

Hypothermia

The anesthesiologist taking care of the patient undergoing PCNL should closely monitor the patient's core temperature. In the anesthetized patient, the esophageal temperature probe is a relatively noninvasive and reliable source for core temperature measurement, second to a blood temperature from a pulmonary artery catheter [32]. Even though PCNL is not considered an open procedure, there is still the potential for the patient to become hypothermic due to continuous irrigation with below body temperature fluid by the surgeon to visualize the renal pelvis. When compared to other urologic procedures utilizing irrigation fluid [TURP, transurethral resection of bladder tumor (TURBT), cystoscopy], PCNL patients have the greatest drop in core temperature [33].

General anesthesia interferes with the body's normal thermoregulation mechanisms. The patient will often shiver to generate heat upon emergence from anesthesia. Hypothermia-induced shivering in the postoperative setting increases oxygen consumption by up to 400% [34]. Frank *et al*. noted that mild hypothermia of

1.3°C can triple the rate of adverse myocardial outcomes in high-risk patients [35]. Mild hypothermia of less than 1°C also can cause platelet dysfunction and coagulopathy, increasing blood loss by approximately 16% and increasing the relative transfusion risk by approximately 22% [36]. Hypothermia is linked to an increased incidence of delayed wound healing and infection, extending the length of hospitalization [37].

During PCNL, it is imperative that the anesthesiologist monitors the patient's temperature and aggressively warms the patient using fluid warmers and forced air warming blankets. Increasing ambient room temperature and prewarming the patient prior to surgery can help prevent patient hypothermia. Warming of irrigant to body temperature can play a crucial role in reducing the degree of hypothermia in PCNL [33].

Potential complications

Percutaneous access to the kidney is a procedure that is performed with imaging assistance rather than under direct visualization. As such, the possibility of unintended injury exists for anatomically close structures. These complications are covered in Chapters 30–-32, but two are especially pertinent to the intraoperative anesthetic management of percutaneous stone extractions. Bleeding requiring transfusion is the most common complication of PCNL and, as such, reinforces the need for communication with the surgeon, frequent assessment of hemoglobin/hematocrit, and availability of blood products should the patient require transfusion. Organ injury requiring surgical intervention is exceedingly rare in experienced hands, but the anesthesiologist should nonetheless be alert to the remote possibility of a lung injury. This is more common in the supracostal approach and can cause a hemothorax or pneumothorax requiring insertion of chest tube to prevent respiratory decompensation [38].

Emergence

The vast majority of patients undergoing PCNL are allowed to emerge from general anesthesia and be extubated in the operating room following the completion of the procedure. For patient safety, the anesthesiologist will occasionally decide to keep the patient intubated for a period of time after PCNL. This additional delay allows the anesthesiologist time to optimize the patient physiologically, vastly improving the conditions for a safe extubation. Issues such as hypothermia, electrolyte imbalances, and the patient's volume status can be assessed and treated as needed with active warming devices, fluid, and blood administration. Postoperative intubation also allows for the patient to be positioned in the supine, head-up position, allowing gravity to alleviate head and airway swelling, which may occur if a patient is in the prone position for an extended period of time during PCNL. A positive cuff-leak test (absence of a leak around an ETT with the cuff deflated) can be used to help determine whether the patient is at a high-risk for upper airway obstruction [39]. Corticosteroids may also be used to help decrease airway swelling and improve the chances of successful extubation [40].

Postoperative care

The postoperative care of the patient who has undergone PCNL should mirror the care of any other patient recovering from any other significant surgical procedure. Owing to a smaller degree of tissue disruption, the PCNL patient should have considerably less pain medicine requirements than patients who have had renal procedures via laparotomy.

Patients with OSA will warrant close observation in the postoperative setting because they are disposed to narcotic-exacerbated hypopneic desaturation and are also at increased risk for sustained arrhythmias and hypertension [41]. These patients may require continuous monitoring overnight in the postanesthesia (PACU) or intensive care unit (ICU) setting as deemed appropriate by the critical care attending. The treatment of OSA in the postoperative period may warrant the use of a continuous positive airway pressure device (CPAP), which may be useful in improving the patient's oxygenation and hemodynamic profile, even if CPAP was not in the preoperative period, by helping to support the patency of the patient's airway [7].

The care provider in the recovery area should be aware that postoperative fever after PCNL is a potential harbinger of urosepsis, which can occur in 0.97–4.7% of patients [42]. Risk factors for post-PCNL fevers include female sex (higher incidence of urinary tract infections) and the presence of a nephrostomy tube (foreign object) [43]. Patients with negative preoperative urine cultures can have preoperative renal stones, which harbor bacteria whose release into the bloodstream is facilitated by the disruption of calculus, resulting in bacteremia and potentially urosepsis [44]. For a patient who has undergone PCNL, the postanesthetic management of fevers consists of supportive measures (fluids, positive inotropes, as necessary), judicious use of antibiotics, removal of the infectious load (foreign bodies and draining urine), and specific sepsis therapy (e.g. hydrocortisone for pituitary/adrenal insufficiency) [45].

Extracorporeal shock-wave lithotripsy

ESWL has undergone significant changes and developments since its introduction in 1980. It has advantages over other forms of lithotripsy, namely the effectiveness of stone fragmentation, simplicity of use, low morbidity, and low mortality. This procedure is the treatment of choice for fragmentation of kidney stones located in the upper portion of the ureter and kidney [46].

The first-generation of lithotripters (Dornier HM -3) used a water bath in a steel tub and a metal gantry chair to support the patient suspended in a sitting position [46]. Second- and third-generation lithotripters (Dornier HM-4, Siemens) eliminated the water bath [46]. However, all lithotripters consists of three components; a shock-wave generator (spark plug), a system to focus the shock wave, and an imaging device to visualize and localize the stone in focus.

The electric energy (from the spark plug or electrode) creates a spark which generates a loud noise, intense heat, and explosive vaporization of water. The sudden expansion of air bubbles creates a pressure wave (shock wave). The shock wave is focused to a focal point called F2 focus (the tip of the electrode is the F1 focus). The shock wave travels through water and body tissues before it reaches the stone. When it reaches the entry surface of the stone, it is transmitted across and exits on the opposite surface of the stone. The repeated shock waves cause the breakdown of the stone's structure, producing small fragments which are passed in the urine. For effective stone disintegration, shock waves should reach the stone unimpeded. Also, for shock waves to be most effective, the stone should remain in the F2 focus during treatment [46, 47]. Kidney stones follow diaphragmatic movement during spontaneous ventilation, which can shift the F2 focus and cause difficulties for stone disintegration [46, 47]. To minimize stone movement, general anesthesia, using low tidal volumes with intermittent breath holding, is recommended during lithotripsy. Theoretical advantages of using controlled ventilation, in addition to reducing stone mobility, are decreased operating room time and shock-energy requirements, resulting in less perinephric trauma and side effects [48]. Intermittent positive pressure ventilation and high frequency jet ventilation have been compared in a few studies and show no difference in successful stone ablation [48]. The high density of the energy shock wave has a significantly greater pain impact with the first-generation lithotripters as it passes through the skin, muscles, and deeper structures, such as subcostal nerves and the kidney capsule [48, 49]. The three factors that influence the propagation of pain at this site are the pressure of the shock waves, size of the focal area, and shock wave distribution. The location and size of the stone have an additional impact. Stones in the renal pelvis are more painful than stones in the lower ureter [48]. General anesthesia as well as spinal and epidural anesthesia are often required for this procedure.

Water baths are no longer produced due to the advances of second- and third- generation lithotripters. However, older first-generation lithotripters continue to be used when second- and third-generation lithotripters fail because of the higher shock energy they produce. Pain from second- and third-generation lithotripters is considered mild to moderate when compared to that of the first-generation lithotripters because the shock waves are of lesser intensity [50]. Tissue infiltrations with local anesthetics, intravenous sedation, and paravertebral blocks have all been used in the outpatient setting with good results. Deep sedation and general anesthesia with an LMA or endotracheal tube are still a consideration for the large and difficult stones.

First-generation lithotripters and physiology of water immersion

Water immersion causes significant physiologic changes to the patient, particularly for the cardiovascular, respiratory, and endocrine systems. The cardiovascular changes are related to the depth of immersion. The central blood volume is increased by redistribution of the venous blood and extracellular fluid from the legs and arms in the sitting position, while the central venous pressure is also elevated due to the water pressure against the thoracic wall [51]. The plasma volume will increase 7%, as hydrostatic pressure favors capillary reabsorption [51]. Cardiac output is increased as a result of the elevations in stroke volume and end-diastolic volume. Bradycardia has also been reported, and may be a compensatory response to the increases in cardiac output and decreases in peripheral vascular resistance [52, 53].

Left atrial distention seen during these water immersion-induced changes will cause increases in diuresis by endocrine pathways, causing stimulation of the volume and pressure receptors, particularly carotid and aortic baroreceptors [54–60] Release of atrial natriuretic peptide causes an increase in diuresis, kaliuresis, and natriuresis. The release of arginine vasopressin is suppressed as a result of increased arterial pulse pressure and left atrial distention. Renin–aldosterone and norepinephrine levels are additional hormones that may be suppressed during immersion and act as mediators.

With regard to respiratory function, blood flow is increased in all zones of the lungs with improvements in the ventilation–perfusion relationship [61 –63]. Vital capacity and expiratory reserve volume (ERV) decrease significantly, while tidal volume (Vt) remains unchanged during immersion [64]. The average reduction in vital capacity and FRC is approximately 30% [64]. There is a marked increase in the dynamic work of breathing (e.g. rapid and shallow breaths) during submersion to the neck, which can be attributed to an increase in flow resistance of the airways as well as an increase in transdiaphragmatic pressure [65]. Patients with preexisting pulmonary and cardiac dysfunction may experience impaired ventilation and oxygenation during water immersion. Therefore, in such patients, second- and third-generation lithotripters are recommended to avoid the physiologic effects of water immersion.

Anesthetic choice

Anesthetic regimens used successfully for lithotripsy include general anesthesia, epidural anesthesia, spinal anesthesia, flank infiltration with or without intercostal blocks, paravertebral blocks (thoracic and lumbar), and analgesia–sedation, with or without topical anesthetic [66–74]. Epidural and spinal anesthesia offer reliable analgesia, and have been frequently used with first-generation lithotripters as well as in patients with severe cardiovascular and pulmonary diseases due to its minimal effect on patient ventilation. For epidural anesthesia, a catheter is placed in the lumbar or thoracic spine in the potential space between the dura and the ligamentum flavum. Local anesthetic can be titrated via the catheter to achieve a desired motor and sensory block; a level of sensory block between T6 and T8 is desirable for kidney stones located in the upper pole. Either lidocaine 2% in a bolus of 15 mL or bupivacaine concentration of 0.25% or 0.5 % can provide excellent anesthesia for approximately 2–4 h, and can be supplemented via catheter if more analgesia is necessary. The extent and intensity of the block can be titrated and maintained as opposed to a single spinal injection. Spinal anesthesia involves direct injection of local anesthetic via a thin needle into the intrathecal space at the level of the lumbar spine below the level where the spine splits into the cauda equina (L1–2). Typical local anesthetics for spinal anesthesia include bupivacaine 0.75% and tetracaine 0.5%, both of which are long-acting anesthetics. The use of lidocaine (shorter acting compared to bupivacaine or tetracaine) for spinal anesthesia is contraindicated due to neurotoxicity. Cauda equina and transient radicular irritation are two complications from the use of lidocaine when injected into the cerebrospinal fluid [75, 76]. Transient radicular irritation is characterized by severe back and buttock pain with no localized nerve damage, and its incidence is seven times greater with lidocaine when compared to bupivacaine and other local anesthetics. The symptoms tend to resolve by the 10th day after spinal anesthesia with no sequelae [75–77].

Administration of local anesthesia in the spinal or epidural space results in a chemical sympathectomy that is well tolerated by most individuals, but can become clinically significant in patients with poor cardiovascular reserve. In these patients symptoms include vasodilation of the lower extremities, resulting in decreased preload as well as afterload, which in turn causes a reduction in cardiac output. Judicious pretreatment with an intravenous fluid bolus can maintain the preload as well as attenuate the precipitous drop in blood pressure. The use of vasoactive medications (e.g. phenylephrine and ephedrine) can also be utilized to augment the blood pressure and systemic vascular resistance. The ability to gradually raise an anesthetic level with an epidural should be considered in the patients in whom rapid hemodynamic changes are undesirable. Disadvantages of using neuraxial anesthesia for outpatient lithotripsy include the time to achieve an adequate level of anesthesia or analgesia, longer recovery phase, and urinary retention. Epidural hematoma can occur and become a devastating complication in the patient with coagulopathies or those receiving anticoagulation. Therefore, neuraxial regional anesthesia is contraindicated in patients with altered coagulation.

There are no absolute indications for spinal or epidural anesthesia, but patients can benefit from these techniques in certain clinical situations. Evidence indicates that neuraxial anesthetic techniques can have improved outcomes in high-risk populations [78]. Benefits of regional anesthesia include a blunting of the stress response to surgery, decreased morbidity, and decreased mortality. When analgesia is extended into the postoperative period, it can reduce the incidence of postoperative thromboembolism in high-risk patients [e.g. morbid obesity, chronic obstructive pulmonary disease (COPD), cardiomyopathy) [78].

Second- and third-generation lithotripters emit shock waves of lower intensity, with lower efficacy as well as smaller focal points, occasionally necessitating additional treatment rounds. As already mentioned, pain is generally less than with the first-generation lithotripters. Analgesia and sedation are still required for patient comfort, as is keeping patient movement to a minimum [79, 80].

Risk factors predictive for increased pain during ESWL include patients of young age, rib-projected stones, recurrent treatments, homogenous stones, and patients with anxiety and/or depression. These patients may exhibit a higher analgesic requirement [81].

Intravenous sedation is a viable alternative for the second- and third-generation lithotripters. The use of intravenous sedation alone provides for a faster recovery period and fewer side effects than found with either regional or general anesthesia [68, 69, 82]. Sedation is commonly achieved utilizing short-acting anesthetic agents. NSAIDs such as ketorolac have anti-inflammatory effects and facilitate stone removal by inducing ureteral relaxation [82]. When used in combination with short-acting opiates such as fentanyl or alfentanil, adequate analgesia can be achieved. COX II inhibitors can also prevent renal colic pain and are useful as a pre-emptive analgesic prior to ESWL [82, 83]. The addition of an adjunct such as midazolam can be used for anxiolysis and amnesia in the perioperative period.

A commonly used medication for moderate-to-deep sedation is propofol, an ultra short-acting hypnotic agent that is administered as a bolus or continuous infusion. It is extremely well tolerated by the majority of patients, providing restful sleep, hypnosis, and amnesia. Propofol has no analgesic properties; therefore, titration of opiates such as fentanyl can be useful. Midazolam has an additive effect for sedation when combined with propofol. Advantages of combining various sedatives and analgesics, called balanced anesthesia, include fewer side effects, the ability to titrate sedation in order to avoid involuntary patient movements, short recovery time, and fast hospital discharge [68, 69, 84–94]. This balanced technique is particularly safe and useful for office-based procedures [95].

Dexmedetomidine (Precedex) is an agent that is gaining popularity among anesthesia providers to sedate patients in the operating room. It is a selective alpha-2 agonist, which has sedating and analgesic properties without respiratory depression. The agonist action of the alpha-2 adrenergic receptor in the sympathetic ganglia modulates the release of catecholamine, resulting in a sympatholytic effect and reduction in blood pressure [72, 73]. Dexmedetomidine is an attractive anesthetic choice for select patients with comorbidities such as morbid obesity, severe COPD, OSA, and patients with tolerance to opiates. Dexmedetomidine produces less respiratory depression than propofol, even at maximal doses. Intravenous sedation–analgesia of dexmedetomidine has proven to be safe and effective for outpatient lithotripsy [71, 74]. In combination with opioids such as fentanyl or remifentanil, dexmedetomidine provides excellent analgesia with minimal side effects [71]. Remifentanil is a potent ultra short-acting narcotic with fast onset and fast elimination, which is administered by continuous infusion, often in combination with dexmedetomidine.

Other anesthetic choices for lithotripsy employ the use of local anesthesia infiltration into the flanks and deep lumbar area. Lidocaine or prilocaine are injected subcutaneously in a dose of 20 mL, which appears to offer adequate pain relief, short onset of action, and low toxicity [88–90]. The local anesthetic is placed 1 cm below the 12th, 11th, and 10th rib with a single needle entry at a 45° angle [90]. The analgesic effect can last up to 3 h and is well tolerated by patients. The procedure is easy to perform and cost-effective.

Intercostal nerve blocks [96] are an alternative for analgesia during ESWL. This block uses bupivacaine 0.25% mixed with epinephrine and lidocaine for faster onset of action. Usually 5 mL is injected in each intercostal nerve at the lower border of the corresponding rib between the posterior axillary line and medial to the angle of the rib. The position of the stone is determined in relation to the lumbar spine. This is a relatively easy block to perform and appears to be well accepted by patients, most of whom report only mild soreness [96]. Additional doses of intravenous opioids can supplement the block for patient comfort.

EMLA cream is a eutectic mixture of lidocaine and prilocaine that is for topical use. Application 45 min to 1 h before ESWL provides adequate effect. An occlusive dressing is also necessary after the application in the flanks for effective skin penetration. A combination of this technique with intravenous sedation and use of opioids seems to be better tolerated and offers advantages over EMLA cream alone [86 –97].

Paravertebral (thoracic and lumbar) blocks can provide adequate postoperative pain relief after lithotripsy, reducing the use of opiates both during and after surgery [98]. Alternatively, a nerve stimulator can be used to guide needle placement [99, 100]. The mechanism of action for paravertebral blocks includes direct penetration of the local anesthetic into the spinal nerve with medial extension through the intervertebral foramina [101]. Five milliliters of local anesthetic is administered per paravertebral level. Anesthetic agents most commonly used are ropivacaine 0.5% or bupivacaine 0.25% or 0.5%, both with epinephrine diluted (1:400 000). Ropivacaine has less cardiotoxicity when compared to bupivacaine and therefore is the preferred choice by many anesthesiologists. Side effects or complications of this block include hypotension, inadvertent injection into the epidural space or spinal block, pneumothorax, and nerve injury. This block offers very effective analgesia and can be combined with small doses of sedation for additional patient comfort. The major advantage of this technique is the prolonged postoperative analgesia [98, 102].

Management of cardiac pacemakers and defibrillators

ESWL can induce cardiac arrhythmias by mechanical stress exerted from the high-energy shock wave into the conduction system. Ventricular and supraventricular tachycardia have been described during ESWL [103–105]. Timing during the cardiac cycle is crucial for inducing dysrhythmias. The shock waves can also inhibit pacemaker output when administered asynchronously. New lithotripters are designed to fire 20 ms after the QRS complex (during the absolute refractory period) [105–108]. This practice reduces risk of arrhythmias due to the R on T phenomenon.

Pacemakers and automatic internal cardiac defibrillators (AICD) are complex devices that interact with cardiac function in ways that can significantly influence hemodynamics [107, 108]. They are designed with a high-frequency noise filter to prevent malfunction from the energy interference [106–108]. Electrical inhibition does not appear to be a problem when ESWL discharge is synchronized to follow a pulse generator signal [107, 108]. However, electromagnetic interference is an important cause of pacemaker malfunction. Fortunately, new pacemakers provide improved shielding to protect them against ESWL damage or reprogramming. The advisory practice for perioperative management of patients with pacemakers and automated defibrillators is to avoid the lithotripsy beam near the pulse generator and disable atrial pacing if the lithotripter triggers on the R wave (internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010).

Patients with an AICD and/or a cardiac pacemaker can receive shock-wave lithotripsy and/or undergo surgical procedures that utilize electrocautery, with some important precautions before the procedure [107, 108, – internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010]. It is important to know the type of device, and battery life and its function. Ideally, the patient can provide this information. However, this information is not always available. Fortunately, there are a limited number of companies that manufacture AICD and all of them have telephone resources that can help identify if a patient has one of their devices. In elective situations, the ACID/pacemaker should be evaluated before and after lithotripsy. Pacemakers should be converted to an asynchronous mode (AOO or VOO), if necessary [107, 108, internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010]. Patients with a rate-sensing pacer should have the sensing function turned off. For AICD patients, the defibrillator functions must be turned off before the procedure due to the risk of it either becoming damaged or being triggered during the shock wave, which can trigger ventricular dysrhythmias [107, 108, internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010].

In an emergency, a magnet can be placed over a standalone pacemaker to convert it to an asynchronous mode. However, the use of a magnet should be discouraged whenever there is adequate time to properly interrogate a pacemaker before and after surgery. After the surgical procedure is completed, pacemakers should be interrogated to be sure they have retained the desired settings.

In an emergency, a magnet can be placed over an AICD to turn off its defibrillator functions. However, applying a magnet over an AICD does not produce exactly the same results on the pacemaker functions in all AICDs, particularly in older models [109]. Therefore, if a magnet is used to turn off the defibrillator, the anesthesiologist and surgeon must take the following into account. First, the pacemaker functions of the AICD can be suppressed by electrocautery, which poses risk for those patients who are pacemaker dependent. Therefore, the surgeon should either limit electrocautery bursts to less than 5 s or use a bipolar electrode. Second, the AICD must be interrogated and reprogrammed at the end of the surgical procedure, but before the magnet is removed [109].

When an AICD is turned off, external defibrillator pads should be placed over the patient's chest, once in the operating room. Optimal position may be an important factor in the prevention of adverse outcomes [59, 61]. Anterior and posterior pads should be used with the appropriate energy output in case the patient requires defibrillation [107, internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010]. Patient cardiac rhythm should be monitored at all times, with pacing and/or defibrillation capabilities immediately available for use [107, internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010]. Once the procedure is finished, the device should be turned on to evaluate for functionality and to restore functionality before the patient leaves the operating room [107, internal communication with Electrophysiology Departments of North Shore – LIJ Health System, April 2010].

Turning off an AICD in a patient who is going to have a water bath lithotripsy is complicated by the fact that external defibrillator pads cannot be used safely in water. This specific scenario requires coordination between the anesthesiologist and cardiologist. An acceptable alternative is to have an experienced user of the external AICD programmer remain on standby once the AICD is turned off for the lithotripsy. In an emergency, the AICD could be turned on again to allow safe defibrillation of the wet patient [109].

Anesthesia for ureteroscopy

With the advent of smaller and semi-rigid flexible ureteroscopes, intravenous sedation is favorable for cases of short duration such as cystoscopy and stent insertion. Ureteral stents, renal calculi, and ureteral strictures have been successfully performed using lidocaine 4% gel to anesthetize the urethra. This anesthetic technique has the benefit of faster operating room turnover and faster discharge from hospital [110–116]. Among men, discomfort during rigid ureteroscopy seems to be related to the passage of the instrument through the membranous urethra and bladder neck [110]. Pain seems to be better tolerated in women having the procedure under local or intravenous sedation [95].

Due to the fact that the kidneys normally move with the respiratory cycle, the stone is only intermittently visualized [46, 47]. Therefore, the anesthesiologist's ability to control tidal volume and respiratory rate under GETA can improve the urologist's ability to successfully fragment ureteral stones. It is imperative that the anesthesiologist and urologist work together to allow concomitant adequate ventilation and intermittent apneic episodes to successfully fragment stones. Urethral trauma with patient movement is a concern during ureteroscopy, emphasizing the importance of selecting an appropriate anesthetic technique for a given patient. If a patient experiences sudden movements under anesthesia with a ureteroscope in use, there is the potential for ureteral trauma or ureteral transection, a potentially devastating and avoidable complication. Selection of anesthetic agent may be tailored to the fact that most of these procedures are performed on an outpatient basis and the patient will be going home on the day of the procedure. However, regardless of the choice of anesthetic technique, it is imperative that the anesthesiologist be vigilant that the patient is adequately anesthetized to avoid such complication.

The urethra receives innervation from the preganglionic sympathetic fibers of the T10–L2 spinal segments. The upper ureter receives parasympathetic input from vagal fibers by means of the celiac plexus and the lower ureter from S2 to S4 [110]. Spinal and epidural anesthesia are rarely the anesthetic choices for ureteroscopy because other modalities offer advantages over neuraxial techniques [110]. However, neuraxial anesthesia remains an option in patients with significantly poor respiratory reserve. General anesthesia has been performed with great success using the LMA, and is a less invasive alternative to endotracheal intubation and is well tolerated by patients for general anesthesia. Sevoflurane and desflurane offer fast onset of action and rapid elimination. Analgesia can be supplemented with small doses of opioids. Compared to regional anesthesia, general anesthesia with an LMA leads to faster patient recovery and discharge [110]. It is an efficient technique for ureteroscopy, cystoscopy, and stent placement in a majority of patients.

The LMA does not protect the airway from the risk of aspiration of gastric content. Therefore, it is important that risk for aspiration be considered when selecting patients for an LMA technique. Factors that increase the risk for aspiration include morbid obesity, liver disease with ascites, diabetes with gastroparesis, pregnancy, GERD, neuromuscular disease, bowel obstruction, and dysphagia. Patients considered at risk for aspiration require GETA or, if possible, regional anesthesia with conscious sedation.

Anesthesia for the patient with spinal cord injury

Patients with spinal cord injury frequently have urologic procedures for stone extraction because they are predisposed to stone formation due to neurogenic bladder and immobilization.

For patients with spinal cord injury, there is a loss of spinal sympathetic discharge modulation, which can produce profound hemodynamic changes [117, 118]. Lesions at the level of T6 and above are associated with a life-threatening, hypertensive emergency, during which uncontrolled sympathetic and parasympathetic hyperactivity occurs in response to stimulation below the level of the spinal lesion [117–119]. This syndrome, called autonomic dysreflexia, results from the lack of supraspinal control of the sympathetic neurons and altered neurotransmission within the spinal cord [119]. Stimuli such as bladder or bowel distention and pain during surgery can trigger severe, uncontrolled hypertension and bradycardia. These patients will experience increases in pulse pressure, sweating, piloerection, vasoconstriction below the level of the spinal lesion, and vasodilation above the spinal lesion. The complications resulting from autonomic dysreflexia include intracranial and retinal hemorrhages, myocardial infarction, coma, and death. Cardiac rhythm anomalies such as atrial fibrillation, ventricular tachycardia, and cardiac arrest can also occur [120].

General and spinal anesthesia blunt the afferent and efferent autonomic neural impulses. These two forms of anesthesia are preferred over other techniques for patients with spinal cord injury. Autonomic dysreflexia can be treated with intravenous ganglion blockers, nitrates, clonidine, and calcium channel blockers. Oral nifedipine given 30 min before cystoscopy has been shown to alleviate the syndrome [121]. Bladder emptying and colonic decompression prior to a surgical procedure can help reduce the risk of developing autonomic dysreflexia.

Conclusions

The patient receiving PCNL presents a challenge for the anesthesiologist. Despite the relatively noninvasive nature of the procedure, there remains the potential for rapid fluid shifts with the patient in the prone position as well as other potential mitigating factors such as hypothermia and possible bacteremia. Close monitoring and attention are essential in both the intra- and postoperative periods, as well as communication with the urologist to ensure the best outcome for the patient.

Anesthesia for ESWL has changed dramatically with advances in lithotripsy. Today, patients with small friable stones can undergo ESWL with intravenous sedation with or without local anesthesia. However, larger stones or stones more resistant to ESWL may require general or neuraxial anesthesia. The eventual anesthetic choice needs to take into account the physical status of the patient, length of procedure, need for minimizing respiratory movement of stone, the need for ureteroscopy, and type of ESWL device utilized. A challenge of increasing frequency is the management of automatic internal cardiac defibrillators during ESWL and/or urologic procedures that utilize frequent bursts of electrocautery. All of these issues can be dealt with safely as long the anesthesiologist and surgeon discuss all of these factors before induction of anesthesia.

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CHAPTER 61

Horseshoe Kidney

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Introduction

Renal fusion anomalies can be broadly divided into two distinct types: horseshoe kidneys and cross-fused ectopia. Horseshoe kidneys are the commonest renal anomalies and have been reported to have an incidence of 1 in 400–700 live births in both autopsy and radiographic data [1, 2]. There is a male preponderance for this condition with a male-to-female ratio of 2:1. No genetic predisposition is known and whilst horseshoe kidneys are frequently diagnosed incidentally and in isolation in adult patients, they may be part of a syndrome in the pediatric population. It is estimated that 23% of patients with horseshoe kidneys have other severe associated malformations, which may be gastrointestinal, musculoskeletal , neurologic, or, most commonly, other urogenital anomalies [3]. Several syndromes are commonly linked to horseshoe kidneys, including Down's syndrome, Turner's syndrome and Trisomy 18.

Development

Normal kidney development occurs at the fourth week of gestation from the fusion of the ureteric bud and metanephric blastema. The kidney is originally formed in the pelvic location and ascends with the growth of the body, in particular the sacral and lumbar region. Primitive renal vessels that originate from the pelvic aorta degenerate as the vascular supply gradually arises from the proximal aorta. As the kidneys ascend through the arterial fork, they may be pushed together too closely and become fused at the lower poles. A more recent theory suggests that fusion may be the result of abnormal migration of the posterior nephrogenic cells, which then fuse with the lower poles of the kidneys to form an isthmus [4]. The ascent of the fused lower pole kidneys terminates just below the inferior mesenteric artery and at the level of the L1–L4 vertebral levels (Figure 61.1).

Horseshoe kidneys are located anterior to the aorta and inferior vena cava. The fused lower poles of horseshoe kidneys are bridged by either functional renal tissue or fibrous tissue. Due to the fusion to the lower poles, the renal pelvis fails to rotate medially and consequently remains ventrally located. This results in the ureter exiting the renal pelvis ventrally and more superiorly, and the longitudinal renal axis converges medially [5]. This has important implications in relation to the management of stones in horseshoe kidneys.

Complications and their management

A horseshoe kidney by itself is asymptomatic; however, due to the anatomy of high ureteric insertion, the presence of the isthmus, and the ventral orientation of the renal pelvis, it is more prone to certain complications, which include recurrent infections [6], renal stones, ureteropelvic junction (UPJ) obstruction, vesicoureteric reflux [7], and even renal malignancy.

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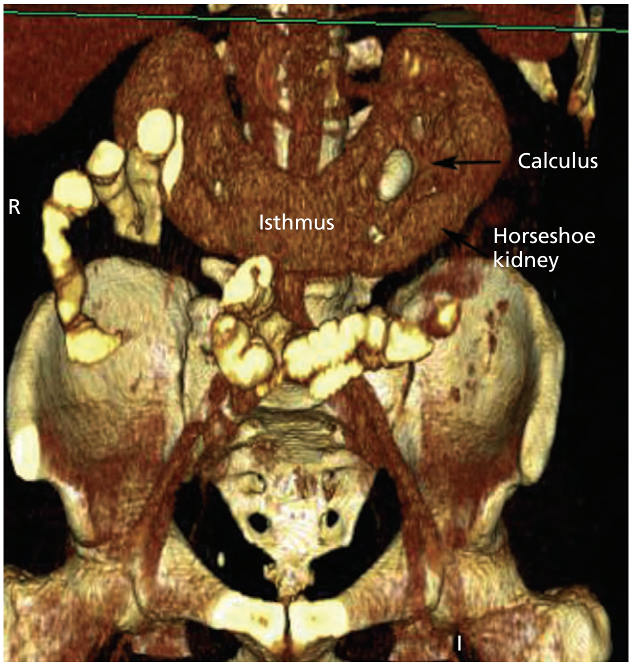

Figure 61.1 Coronal view of a horseshoe kidney 3D reconstruction with a calculus in the left moiety.

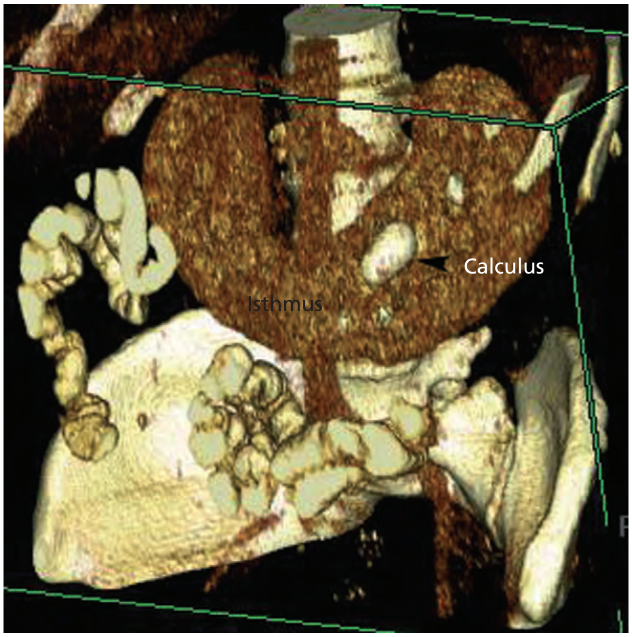

Figure 61.2 Coronal oblique view with 3D reconstruction showing the ventrally orientated lower pole and isthmus.

Urolithiasis

Urolithiasis is the commonest complication related to horseshoe kidney and is estimated to occur in between 21% and 60% of cases [8]. This is likely to be a consequence of impaired urinary drainage, leading to stasis and infection predisposing to calculi formation. The treatment of urolithiasis poses a unique challenge due to the variable vascular and renal anatomy of horseshoe kidneys and their predisposition to multiple and large staghorn-like calculi [3]. The abnormal orientation of the renal pelvicalyceal system further increases the potential complexity for stone management.

Minimally invasive intervention for the treatment of urolithiasis in a horseshoe kidney is now widely accepted, with good stone-free results and low complication rates [9, 10]. However the clinical decision-making process must balance the likelihood of stone-free rates against the intervention risk and potential for complications.

Extracorporeal shock-wave lithotripsy

Extracorporeal shock-wave lithotripsy (ESWL) has revolutionalized the treatment of renal stone disease and has been advocated as the primary treatment modality for stones less than 20 mm in diameter [8]. Sheir *et al.* retrospectively reviewed 198 patients with anomalous kidneys and showed that ESWL is a safe and reliable method of treatment with a stone-free rate of 72% [11]. This is comparable to the stone-free rate of a solitary stone in a normal kidney (72.8%); however, the reported range for stone-free rates in horseshoe kidneys varies between 33% and 79% [12].

The anatomy and orientation of a horseshoe kidney presents a challenge to the use of ESWL as the renal pelvis is venteromedially orientated and approximately a third may have concomitant UPJ obstruction. Locating these calculi can be difficult as the vertebrae may act as an obstacle and there may be associated vertebral anomalies in some patients. The skin–stone distance may also be increased, resulting in difficulty in positioning the focal point (Figure 61.2). Prone position and ”blast path” may need to be used to target these awkwardly positioned calculi [13]. A better stone-free result is also achieved when a second-generation lithotripter is used [11]. Concerns have also been raised, due to the high ureteric insertion of the ureter, as to whether fragments post ESWL can pass spontaneously. The most important predictors for failure of ESWL or significant residual calculi needing retreatment are the position, length, and number of stones. Ancillary procedures may need to be used pre ESWL, such as percutaneous nephrostomy, double-J ureteric stents, or ureteral catheterization, and their use should be decided on a case-by-case basis. It is important to emphasize that there have been no prospective studies comparing the different treatment modalities in this group of patients.

Complications post ESWL in horseshoe kidneys are similar to those seen in normal kidneys. Renal colic, mild hematuria, and urinary tract infection are considered mild and may be treated conservatively and medically. Steinstrasse is a rare but known complication post ESWL and can result in ureteric obstruction requiring endoscopic retrieval of these calculi. The risk factors for steinstrasse post ESWL in a normal kidney are stones greater than 2 cm in a dilated system, proximal located calculi, and the use of a high kilovoltage for disintegration [14].

Percutaenous nephrolithotomy

Percutaneous nephrolithotomy (PCNL) is a well-established technique for the treatment of urolithiasis in normal kidneys and is often used as first-line treatment in horseshoe kidneys, especially when calculi are larger than 2 cm or after failed ESWL.

As described above, the horseshoe kidney lies lower than the normal kidney. The renal pelvis is ventrally orientated and in most cases, the lower poles are connected by isthmus which may be fibrous or viable renal tissue. The long axis of the kidney is orientated in the sagittal plane, such that the posterior calyces are orientated dorsomedially and the frontal row points dorsolaterally. Thirty percent of horseshoe kidneys have a single renal artery on either side [15], but the blood supply is variable with accessory vessels arising from any part of the abdominal aorta, bifurcation or iliac arteries, and inserting into the renal hilum. There are no accessory vessels in the dorsal aspect of the horseshoe kidney [16].

Taking all the above anatomic features into consideration, percutaneous access of horseshoe kidney is relatively safe and is often approached via the most superior calyx. Inadvertent damage to the pleura is uncommon with an upper pole puncture in a low-lying horseshoe kidney. The posterior calyx is relatively easily accessible with a direct puncture in a dorsoventral direction and the puncture site more medially located in comparison to a normally orientated kidney. Apart from several accessory vessels to the isthmus, there are no major blood vessels arising from the dorsal aspect of the kidney. The risk of access-related major vascular hemorrhage is no higher than in normal kidneys.

Access for PCNL can be performed under ultrasound, fluoroscopic, or computed tomography (CT) guidance. The basic principle of achieving an atraumatic puncture of the renal calyx should be adhered to if possible, regardless of the modality used. The safest point of puncture is the middle of the calyx following Brödel's line. However, the superior calyx is usually the chosen puncture site for staghorn calculi or stones within multiple calyces. This is because of anatomic access with a posterior puncture, which allows increased maneuverability of the nephroscope within the collecting system and the option to use flexible instrumentation to access stones in peripheral calyces.

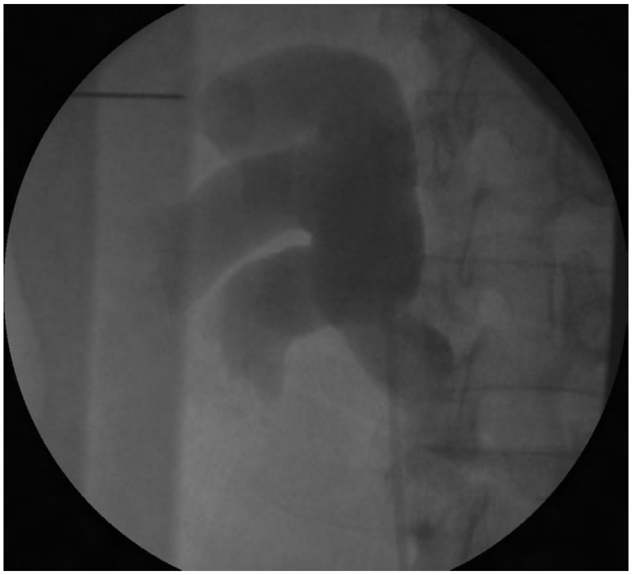

Figure 61.3 18G-sheathed needle is aimed at the calyceal cup.

Ultrasound can be used to guide puncture into the superior calyx if the collecting system is hydronephrotic or predilated with fluid/contrast retrogradely. However, the lower pole is also often poorly delineated and as a consequence, the view of the calyx may be suboptimal to guide access puncture [17].

Fluoroscopic-guided puncture is the standard technique used in our institution. After placing a ureteric catheter, the patient is then turned into the prone position with the C-arm placed vertically. The pelvicalyceal system is distended with contrast and the C-arm can be rotated +30° to –30° to evaluate the calyceal anatomy. An 18G sheath needle is used to puncture the skin and advanced into the desired calyx under fluoroscopic guidance (Figure 61.3). The needle is advanced in increments and aimed at the calyceal cup. When the needle is moving with respiration, the C-arm is then rotated obliquely to an angle such that the length of the needle is visualized and the needle is advanced under fluoroscopic guidance. The needle should be advanced ideally to puncture the epicenter of the calyx and the needle tract should be in the orientation of the infundibulum. As the tract may be longer for horseshoe kidneys, longer instruments may be necessary. As the lower pole and pelvis are more anteriorly facing than is usual, a standard lower pole lateral entry may damage the large anterior division arteries or accessory branches from the iliac artery [18]. Therefore, lower pole calyx puncture is avoided in our practice unless there is no alternative. Once the puncture site is secured, an Amplatz super-stiff guidewire (0.035 inch, 180 cm; Boston Scientific, Natick,

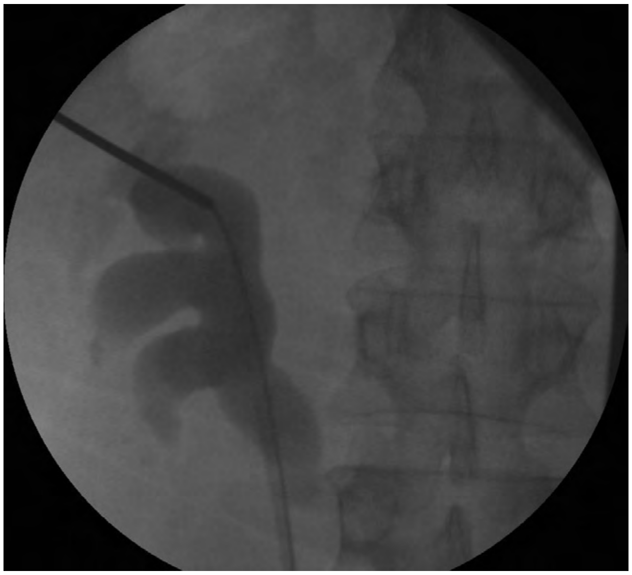

Figure 61.4 Telescopic metal dilator is inserted within the upper pole calyx with an Amplatz super-stiff guidewire in the ureter to anchor the tract.

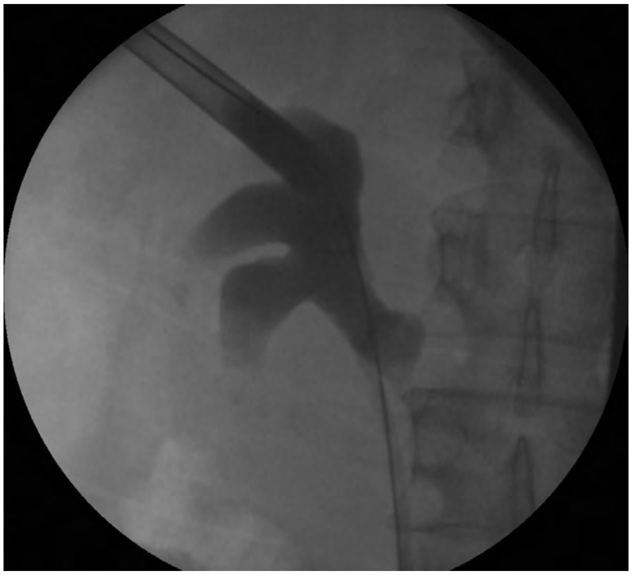

Figure 61.5 26F Amplatz sheath is inserted into the upper pole calyx .

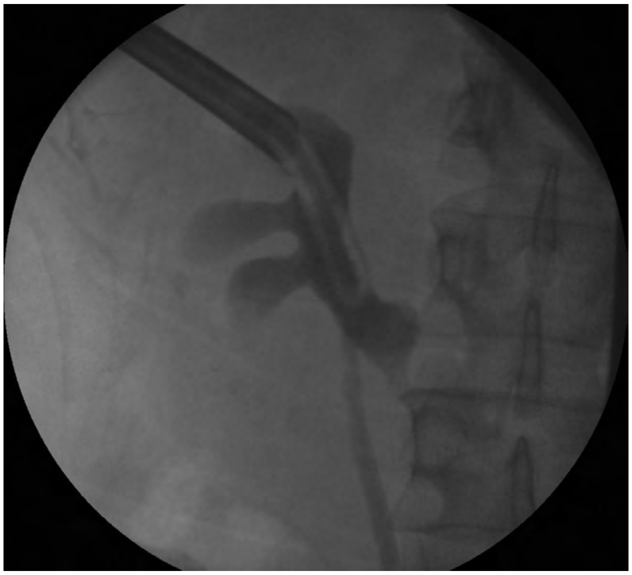

Figure 61.6 Foley catheter is sited as a covering nephrostomy at the end of the procedure.

MA, USA) is advanced, preferably down the ureter (Figure 61.4), and the tract is dilated serially with telescopic metal dilators (Olympus, Keymed, Southend-on-Sea, UK) to accommodate the 26F (up to 30F) Amplatz sheath (Cook Urological, Bloomington, IN, USA) (Figure 61.5). A rigid nephroscope is used to remove the calculi, using either an ultrasonic or lithoclast lithotripter to disintegrate the stones. Stones can be removed sequentially through the tract with various stone-grasping devices. At the end of the procedure, we usually site a Foley catheter (20F) as a covering nephrostomy to tamponade the tract for at least 24 h (Figure 61.6). This is then clamped and if the patient is asymptomatic, the nephrostomy is be removed on the ward. A postprocedural nephrostogram is only performed if there is concern with regard to injury or significant distal ureteric stones causing obstruction.

CT-guided access is reserved for complex situations resulting in challenging access due to the patient's associated vertebral anomaly, severe kyphoscoliosis, extreme obesity, or hepatosplenomegaly. A CT scan is normally acquired in a prone position and can also be used for surgical planning prior to PCNL. Retrorenal or posterolateral displacement of the bowel can be associated with horseshoe kidney and the bowel may occasionally act as an obstacle to percutaneous access. In these situations an initial unenhanced CT abdomen and pelvis with 2-mm reconstruction (CTKUB) may be performed as an overview. Subsequent images for CT-guided procedure can be acquired by obtaining a volume of area of interest and reconstructed with 3-mm slice thickness. It is paramount in this case that the patient can tolerate a prolonged prone position. Once access is obtained, a nephrostomy tube can be left *in situ* for subsequent access and the tract can be dilated as described above under general anesthesia.

The stone-free rate post PCNL in the treatment of renal calculi in horseshoe kidneys is similar to that in normal kidneys at 80%. The complication rates reported are also comparable with those of normal renal PCNL: minor complications such as hematuria and infection in 15%, and major complications such as hydropneumothorax requiring insertion of a chest drain in 2% [19].

Ureteroscopy

Retrograde digital flexible ureteroscopy is becoming a more frequently used modality, especially for stones less than 15 mm in diameter using the holmium laser for stone disintegration. However, reported case numbers are small and retrospective, and there may be issues relating to ureteric access requiring prestenting. These cases will generally require use of an access sheath and postoperative stent insertion. To date, such cases have generally been managed in specialist stone centers that can offer the full range of a stone management service [20].

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CHAPTER 62

Associated Conditions and Treatment of the Pelvic Kidney

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Introduction

The incidence of a pelvic kidney is estimated to be between 1 in 2200 and 1 in 3000 [1]. Given the rarity of a pelvic kidney, it often is an unsuspected finding in patients presenting with vague or atypical abdominal symptoms. Only on further evaluation with radiographic examination is an ectopic kidney identified as the cause [2].

Because of structural and architectural anomalies that can accompany a pelvic kidney, conditions such as chronic obstruction and nephrolithiasis are common. The variation in anatomy of a pelvic kidney creates anomalous vascular patterns and altered spatial relations with adjacent pelvic organs. Therefore, it is important for the urologist to consider ectopic kidney as part of the differential diagnosis in patients with abdominal or pelvic pain and to be familiar with the appropriate work-up and treatment of common associated conditions. This chapter reviews the diseases associated with pelvic kidneys, in particular calculus disease and ureteropelvic junction obstruction (UPJO), and discusses the management options.

Renal development

During weeks 6 and 9 of human development, the kidney ascends from a pelvic position to the lumbar region in a site just inferior to the adrenal glands. Simultaneous with ascent, the kidney rotates medially on its long axis. As the kidney migrates cephalad, the vasculature supplying the organ arises from successive transient aortic offshoots. Blood vessels that are no longer able to reach the migrating kidney will degenerate.

If there is incomplete renal ascent, the kidney will reside in an ectopic position. If the kidney does not ascend at all, it will remain in the pelvis and is referred to as a pelvic kidney. A pelvic kidney lies posterior to the peritoneum, anterior to the sacrum, and caudal to the aortic bifurcation. As a consequence of failure to ascend, the pelvic kidney remains unrotated and often preserves its fetal blood supply from the iliac vessels or the distal aorta [3] (Figure 62.1).

The reasons for failure of the renal ascent from the pelvis have not been well elucidated. Hypotheses include abnormalities of the ureteral bud and metanephric blastema, genetic variants, teratogenic effects, and anomalous vasculature physically blocking ascent [4]. It has been suggested, though, that the initial blood supply to the kidney does not affect its movement to a final position and therefore is unlikely to be the cause of an ectopic position [3].

Nephrolithiasis

The ectopic kidney is thought to be no more susceptible to disease than the normally positioned kidney, except for the presence of calculi and hydronephrosis [3]. A horseshoe kidney has a 20% reported incidence of associated calculi; however, the incidence of stones in pelvic kidneys has not been established [5]. Urinary calculi

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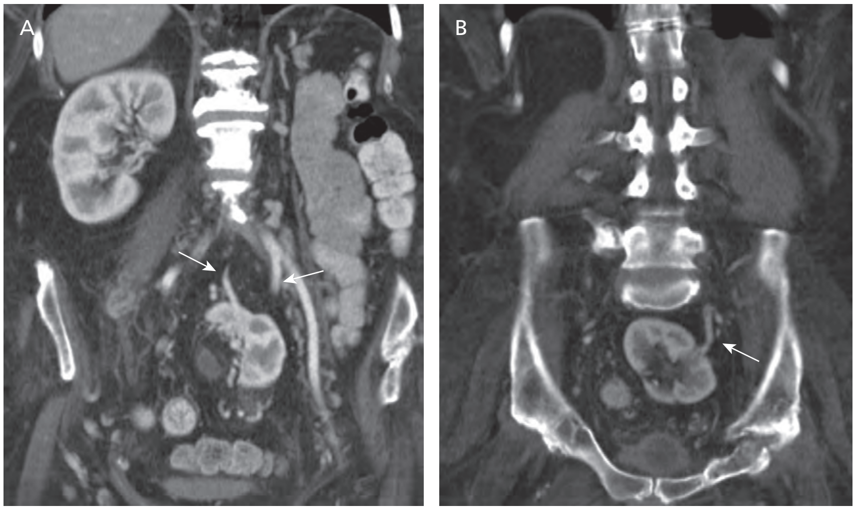

Figure 62.1 (A, B) CT scan of left pelvic kidney demonstrating aberrant vasculature (arrows).

commonly occur in association with urinary stasis or infection in patients with upper urinary tract abnormalities [6]. While renal calculi in horseshoe kidneys have demonstrated metabolic abnormalities predisposing to stone formation, such as hypovolemia, hypercalcuria, and hypocitraturia, no available studies have specifically analyzed metabolic abnormalities in renal calculi of pelvic kidneys [5].

It is the anterior position of the renal pelvis, malrotation of the kidney, high insertion of the ureter, anomalous renal vasculature, or a combination of these factors that can impair the drainage of urine and partially obstruct the pelvic kidney. Although the pelvic kidney is situated in the retroperitoneum, loops of bowel lie between the anterior abdominal wall and the kidney. The pelvic kidney also is more protected by the bony pelvis, with less potential space for maneuverability (Figure 62.2). Because of the greater risk of injuring aberrant vessels or overlying abdominal viscera and nerves, the pelvic kidney presents additional treatment challenges for the urologist. Therefore, alternative approaches to treating nephrolithiasis in the pelvic kidney may yield better outcomes than standard approaches to anatomically normal kidneys.

Extracorporeal shock-wave lithotripsy

While extracorporeal shock-wave lithotripsy (ESWL) remains a treatment option for stones in anatomically variant kidneys, there are only limited single-institution reports of its use in pelvic kidneys. Renal calculi pose significant technical challenges for nonsurgical treatment modalities such as ESWL, as the kidney is guarded by the bony pelvis and often has surrounding fibrous bands that impair pyeloureteral motility [7]. Demirkensen *et al*. published their series comparing ESWL outcomes in normal versus abnormal urinary tracts [8]. Renal calculi situated under the pelvic brim were treated in the prone position, whereas stones above the pelvic brim were treated in the supine position. Of the eight pelvic kidneys, 38% were stone free 12 weeks after ESWL, 50% had nonobstructive and noninfectious clinically insignificant residual fragments (CIRF) of 4 mm or smaller, and 13% (one patient) failed ESWL. Failure is defined as no fragmentation after three sessions. The pelvic kidney that failed ESWL contained a staghorn calculus. Overall success rates of ESWL (defined as % stone free + % CIRF) for normal and upper urinary tracts were 96% and 93%, respectively ($P > .05$). Normal kidneys did have higher stone-free rates than abnormal kidneys (78% vs 56%), whereas abnormal kidneys had a higher rate of CIRF (37% vs 18.5%). The cause of higher

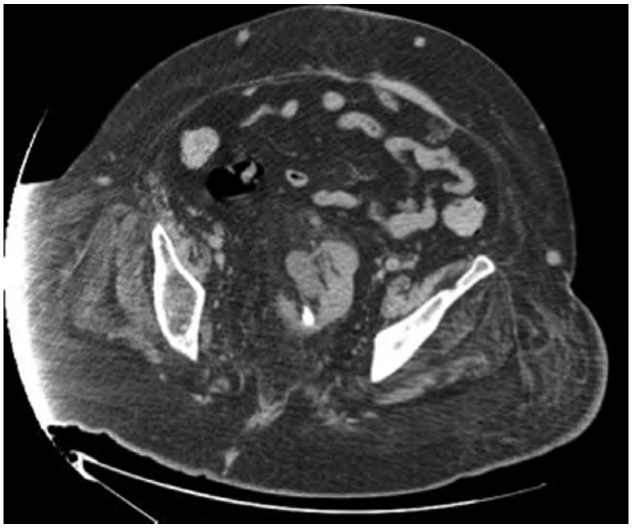

Figure 62.2 Calculus within pelvic kidney seen on CT scan.

rates of residual fragments in abnormal kidneys is hypothesized to be a result of abnormal drainage patterns in anatomically variant kidneys, including pelvic kidneys. Therefore larger stones should be considered for alternative treatment options.

Other groups have also reported success with ESWL for stones in ectopic kidneys with clearance rates exceeding 75% for stones with a mean stone burden of 1.4 mL [9]. While many publications state ESWL may be considered as first-line treatment for stones in anomalous kidneys without major complications, the vast majority of the renal anomalies are horseshoe kidneys, malrotated kidneys, or crossed fused ectopic kidneys, with rare cases of pelvic kidneys [10].

However, Talic refuted the notion that abnormal drainage in pelvic kidneys reduces success rates of ESWL, reporting the largest single-institution study to date of ESWL for stones in pelvic kidneys [11]. Talic's series reported a 100% success rate (82% stone free, 12% CIRF) in 14 stone-bearing pelvic kidneys at 3 month follow-up. The high success rate was attributed to appropriate patient positioning during treatment and accurate stone localization. Most of these patients were treated with ESWL in the prone position, permitting anterior entry of shock waves. Additionally stones that were projected over the sacroiliac joint had ureteral catheter placement to aid in the fluoroscopic localization of the stone. Five of the 14 patients required more than one session of ESWL to obtain the reported results.

Some authors claim that even though ESWL can be used for treatment of horseshoe and malrotated kidneys, it is not successful for the majority of stones in pelvic kidneys [12]. Although ESWL does demonstrate satisfactory fragmentation of stones in both normal and abnormal kidneys, abnormal kidneys have higher rates of residual fragments secondary to poorer rates of stone clearance. Residual fragments promote stone recurrence and stone growth and act as a nidus for infection, so patients with stones in ectopic kidneys treated with ESWL warrant close follow-up [13].

Ureteroscopy

The endourologic management of stones in pelvic kidneys presents unique challenges not encountered in normally positioned kidneys. The tortuous ureter often associated with a pelvic kidney hinders deflection of the flexible ureteroscope, potentially limiting access. If the trajectory to the renal pelvis requires greater than two turns of the ureteroscope before it reaches the final calyx, ureteroscopy is limited by the mechanical capacity of the ureteroscope to deflect. There are, however, select reports of successful ureteroscopic stone treatment in pelvic kidneys. Weizer *et al.* noted that with the development of holmium laser lithotripsy, actively deflectable, small caliber flexible ureteroscopes, nitinol baskets, and graspers, retrograde access to calculi in pelvic kidneys can be successful [14]. Their series, one of the largest single-center publications to date, included four patients with symptomatic calculi in pelvic kidneys who failed ESWL. Using a 7.5F flexible ureteroscope, a 200-μm holmium laser fiber, nitinol graspers and baskets, and ureteral stent placement, three patients were rendered stone free, confirmed by plain film or noncontrast computed tomography (CT) scan at 2-month follow-up. Of note, the one failure occurred in a patient who had a 6-mm residual fragment from an original stone burden of 1.5 cm. In another series of four patients with a pelvic kidney treated ureteroscopically for large obstructing stones (>3-cm diameter), three patients were successfully treated with holmium laser lithotripsy, defined as stone free at 3-month follow-up [15]. Holmium:YAG laser lithotripsy was performed in a retrograde manner using energy ranging from 1 to 1.5 J/pulse, frequency ranging from 15 to 20 Hz, and with a mean operative time of 120 min (100–180 min). In cases of anomalous kidneys associated with tortuous ureters, placement of a ureteral access sheath may straighten the ureter, thereby facilitating access to the renal pelvis. The access sheath offers the additional benefit of keeping the ureteroscope straight, which improves deflectability within the renal pelvis.

In patients with a large body habitus, uncontrolled hypertension, altered renal anatomy, or coagulopathy, ESWL efficacy may be limited, lending additional support to a ureteroscopic approach [16]. Likewise, in patients with significant cardiopulmonary disease who may not tolerate prone positioning for percutaneous nephrolithotomy (PCNL) or in patients with coagulopathies who are at risk for hemorrhage, ureteroscopy may constitute a reasonable alternative. Although ureteroscopy has been successful for stones in pelvic kidneys, additional approaches may be necessary for complete fragment clearance.

Laparoscopic nephrolithotomy

Laparoscopy-guided treatment of stones in pelvic kidneys permits visual exposure of the kidney, enhancing safe puncture and correct tract placement integral to PCNL. Laparoscopic-assisted PCNL for the treatment of stones in a pelvic kidney was first described by Eshghi *et al.* [17]. A staghorn calculus was removed using percutaneous techniques under the guidance of the laparoscope, which permitted bowel displacement. In 1992, a case series with an additional two patients was published [18]. One of the patients had a complete staghorn calculus in the pelvic kidney. Since nephroscopic examination only permitted access to parts of the stone, complete stone clearance would have required multiple tract

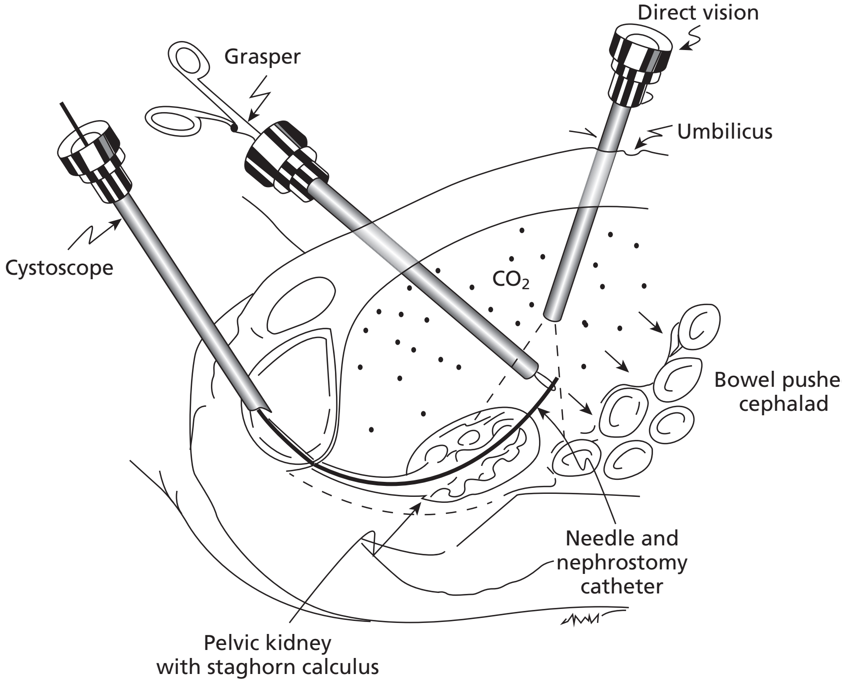
Direct vision
Grasper
Umbilicus
Cystoscope
CO_2
Bowel pushed cephalad
Needle and nephrostomy catheter
Pelvic kidney with staghorn calculus

Figure 62.3 Percutaneous access to the pelvic kidney using combined retrograde and laparoscopic techniques (adapted from Lee and Smith [18], with permission).

dilations. The patient then underwent a successful open pyelolithtomy with multiple nephrotomies.

The technique of retrograde nephroscopy being utilized along with laparoscopy to assist percutaneous access permits continuous visual control and facilitates displacement of overlying bowel. Laparoscopy-assisted anterior retrograde percutaneous nephroscopy involves retrograde percutaneous access using a Hunter–Hawkins retrograde nephrostomy needle with adjunctive laparoscopy to manipulate overlying bowel [19] (Figure 62.3). Following fluoroscopic guidewire placement and insertion of a sheathed catheter into the desired calyx, the curved tip Hunter–Hawkins needle is advanced through the middle of the papilla. The needle is then grasped under laparoscopic vision as it is pushed through and exits the surface of the renal parenchyma. The needle is then pulled through the anterior abdominal port along with the guidewire and catheter. A larger catheter is advanced over the first catheter, and the Hunter–Hawkins needle and "rocket" guidewire are removed. This leaves a tract extending from the urethral meatus to the anterior abdominal wall. Using fluoroscopic guidance, the tract can be dilated and the kidney stones removed through a combination of ultrasonic lithotripsy and mechanical extraction. A nephroureteral stent is placed, and a nephrostogram confirms placement of the distal end in the ureter and the portion with holes in the renal pelvis.

Similar reports of transperitoneal laparoscopic access have since been published. Holman and Toth described 15 patients treated with laparoscopy-assisted percutaneous transperitoneal surgery in the Trendelenburg position to facilitate displacement of bowel away from the pelvic kidney [20]. In 1996, Zafar and Lingeman modified the laparoscopic technique of PCNL with the addition of intracorporeal suturing of the nephrostomy site and placement of a ureteral stent, thereby eliminating the need for a transperitoneal nephrostomy tube [1].

In 2002, Troxel *et al.* described an extraperitoneal laparoscopy-assisted percutaneous technique to access the lower pole calyx of a pelvic kidney [21]. These authors cautioned that a transperitoneal approach to the pelvic kidney adds unnecessary risk and morbidity because of the potential for injury to the bowel and violation of the natural peritoneal barrier. This could result in hemorrhage, peritoneal urine leak, peritonitis, or postoperative ileus. Extraperitoneal access to the pelvic kidney reduces the risk of intestinal injury and leaves the peritoneal cavity intact. It has the added benefit of reduced fluid drainage compared with transperitoneal access, and may be a better procedure for patients who have had prior abdominal surgeries with resulting adhesions.

Both anterior and posterior approaches to laparoscopic PCNL in the pelvic kidney have been reported. In 1993, Toth *et al.* described removal of two stones from a pelvic kidney via an anterior transperitoneal approach in which the anterior surface of the kidney was exposed by laparoscopic mobilization of the overlapping sigmoid colon [22]. Puncture of the desired calyx in the pelvic kidney was performed in an antegrade fashion, using both fluoroscopic and laparoscopic control. In their series of three patients, Mousavi-Bahar *et al*. recommended that before starting dilation of the nephrostomy tract, gas pressure should be decreased to reduce the distance between the skin and the renal system. This makes it possible to easily reach the whole collecting system [23].

In 1993, Goel *et al.* described a variation of the anterior approach in which the tract to the pelvic kidney was established transabdominally and advanced transmesenterically between major mesenteric vessels to permit exposure of the kidney [24]. The proposed benefit of transmesenteric access is a reduced risk of bowel injury associated with bowel manipulation and mobilization. An anterior approach to laparoscopic PCNL for pelvic kidneys may be better suited to patients with a slender body habitus, in whom there is less mesenteric fat, as this may lead to better visibility of the mesenteric vessels and a potentially lower risk of vascular injury.

A posterior approach to laparoscopic PCNL for a pelvic kidney was described by Monga *et al*., who removed a calcified stent from a pelvic kidney via a prone suprailiac approach [25]. A posterior approach to laparoscopic PCNL is not indicated if the pelvicalyceal system is not completely overlapped by the sacrum and its alae. A posterior approach is less advantageous in an obese patient, in whom the transgluteal distance to the pelvic kidney is likely to be greater than with a standard flank incision.

In patients with a complicated history of abdominal procedures or those in whom solid viscera or bone is obstructing optimal renal access, laparoscopy-assisted PCNL may permit improved access. Transhepatic laparoscopy-assisted PCNL and transiliac laparoscopy-assisted PCNL via an iatrogenically created defect in the ileum have been described [26].

Commonly reported complications of PCNL include fever, bleeding, infection, clot colic, catheter dislodgment, and urinary extravasation. A case of incomplete femoral neuropathy has been reported, probably as a result of direct traumatic injury to the dorsal columns of the lumbar plexus [25]. With more medial posterior approaches adjacent to the paraspinal muscles, inadequate length of the nephroscope may inhibit intrarenal manipulation. Additionally, a more medial posterior approach that creates a tract adjacent to the paraspinal muscles and alongside the quadratus lumborum or psoas major muscles places several nerves at risk for injury. The iliohypogastric and ilioinguinal nerves lie anterior to the quadratus lumborum, the genitofemoral nerve lies anterior to the psoas major, and the femoral nerve lies lateral to the psoas major muscle. Consequently, with the anomalous location of an ectopic kidney, meticulous attention must be paid to understanding the specific anatomy in order to reduce the risk of injury to structures that lie along the access tract. Monga's group stressed the importance of conveying to patients the potential for nerve damage during a percutaneous approach to the ectopic kidney.

Desai and Jasani reported the use of ultrasound guidance rather than fluoroscopy for PCNL in 15 patients with ectopic kidneys [27]. Ultrasound guidance can help depict viscera, and the ultrasound probe itself can be used to deflect bowel away from the kidney. However, ultrasound-guided PCNL may be associated with a risk of injury to overlying collapsed bowel, which may not be adequately visible with ultrasound. Additionally, ultrasound-guided PCNL is inferior to a laparoscopy-guided PCNL in the event a second tract is necessary. The endoscopic vision provided by laparoscopy can permit a safer transmesenteric puncture and tract dilation compared with ultrasound imaging, which provides less clarity and cannot facilitate creation of an additional tract [21].

Laparoscopy as an adjunctive tool in the endoscopic treatment of difficult stones has yielded stone-free rates between 91% and 100% in the few available case series. Gupta *et al*. reported a 100% stone-free rate in a cohort of four patients with pelvic kidneys who underwent laparoscopy-assisted PCNL [28]. Two of these patients had failed prior ESWL. The mean stone size was 2.1 cm. The upper calyx was accessed in all four cases, with three stones in the renal pelvis and one in a calyx. Matlaga *et al*. reported a series of laparoscopy-assisted PCNL in eight patients with a 100% stone-free rate. These patients were left “tubeless,” without external drainage nephrostomy tubes, and instead had internal double-J ureteral stent placement [26].

Laparoscopic pyelolithotomy

In 1996, Harmon *et al*. reported laparoscopic pyelolithotomy in a patient with a pelvic kidney who had undergone two unsuccessful attempts at ESWL and one failed ureteroscopy [29]. Given the prior treatments, adhesions were dense and visibility was poor. Laparoscopy was useful in permitting direct viewing of aberrant vessels and peripelvic inflammation. Once the pelvic kidney was dissected and exposed appropriately, a 2-cm pyelotomy was created, and the calculi were extracted with grasping forceps. The depth and location of the pyelotomy made it difficult to perform endoscopic or suture closure, so the renal pelvis was left open. When the renal pelvis was not easily visible, the ureter was identified, traced proximally to the renal pelvis, and isolated with a vessel loop. Because the stones were large and solitary, the vessel loop was used for traction and identification rather than prevention of stone migration [30]. Presence of a ureteral catheter permits flushing to clear residual

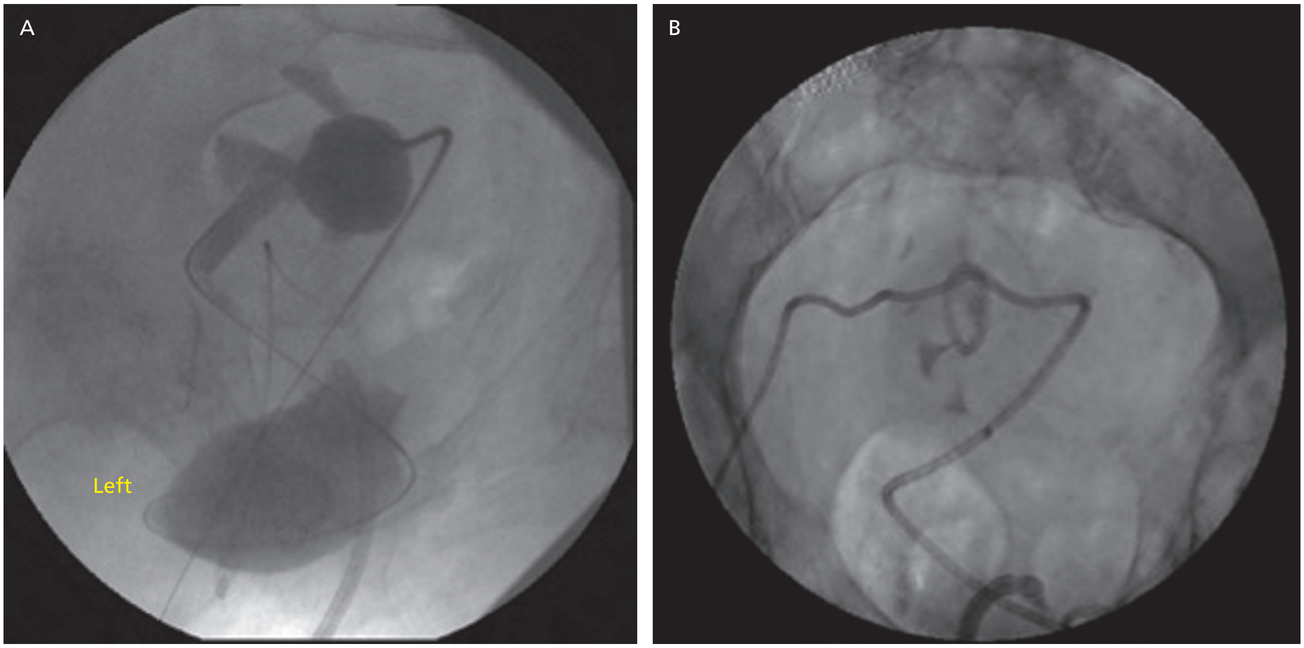

Figure 62.4 Guidewire and nephroureteral stent placement demonstrating ureteral tortuosity in a pelvic kidney. Percutaneous access was gained via the transgluteal approach via the greater sciatic foramen. (A) Lateral view with a guidewire, and a Foley catheter in bladder. (B) Anteroposterior view with a nephroureteral stent in place and a Foley catheter in bladder.

fragments, and a flexible cystoscope or ureteroscope permits identification of hidden calculi. Ideally, the pyelotomy is closed with sutures. However, if this is not possible because of its location, an internal double-J stent should be placed along with a bladder catheter for 2 weeks to promote closure of the pyelotomy. A suction drain is positioned in the perinephric area through a working port to prevent urine leak [31].

Laparoscopic pyelolithotomy in a pelvic kidney has been cited as an approach that is well suited for accessing anteriorly or laterally displaced renal pelvises in ectopic kidneys [32–34]. A laparoscopic transmesocolic pyelolithotomy, if feasible, is an option that avoids colon mobilization [35]. Intraoperative fluoroscopy permits identification of the renal pelvic and allows for periodic re-evaluation of pending stone burden. With improvement in laparoscopic suturing techniques and laparoscopic suturing devices, pyelotomies are sutured closed in a running fashion.

In a small series comparing laparoscopy-assisted PCNL versus laparoscopic pyelolithotomy, laparoscopic pyelolithotomy is reported as the ideal treatment for large renal pelvic stones in ectopic kidneys because it has the advantage of avoiding renal parenchymal puncture [1]. However, the number of published cases for laparoscopic pyelolithotomy is small, with the need for intracorporeal suturing making it a more technically challenging procedure. Therefore, the mean operative time for laparoscopic pyelolithotomy (n = 6) was longer than for laparoscopy-assisted PCNL (n = 5) in the present study (mean operative time 141 min vs 183 min, respectively, $P = .01$) [36].

Transgluteal percutaneous nephrolithotomy

An alternative posterior approach to laparoscopic PCNL was described by Watterson *et al*. who fluoroscopically accessed the pelvic kidney via the greater sciatic foramen [37]. After CT evaluation and analysis to optimize tract placement, fluoroscopic guidance was used to establish the tract, thereby avoiding injury to nearby bowel loops or blood vessels. Following interventional radiologic principles of deep pelvic abscess drainage, the approach through the greater sciatic foramen rendered the patient stone free with an uncomplicated postoperative course. Recommendation is to place the tract as close to the sacrum as possible to avoid vascular or neurologic structures. More recently, at our institution we performed percutaneous stone extraction in a pelvic kidney via the greater sciatic foramen (Figure 62.4). The patient had an uncomplicated hospital course and remained stone free on follow-up imaging (unpublished observations).

Ureteropelvic junction obstruction

UPJO is associated with some renal anomalies and has been reported to occur in 22–37% of ectopic kidneys [38]. Endoscopic incision of the UPJ for relief of obstruction has been used since the early 1980s [39]. UPJO in a congenital pelvic kidney presents additional treatment difficulties beyond those of anatomically normal kidneys because of variations in vasculature and altered spatial relations with surrounding organs as a result of malrotation and the kidney's anomalous location.

Percutaneous endopyelotomy

To date, there have been few reports addressing the treatment of UPJO in patients with congenital renal anomalies, with exceedingly rare reports of the treatment of UPJO in a pelvic kidney. Salas *et al*. performed percutaneous endopyelotomy in six patients with horseshoe kidneys [40]. In 1998, Jabbour *et al*. reported a series of antegrade endopyelotomy in ectopic kidneys using a laparoscopy-assisted approach with a Hunter–Hawkins catheter to obtain access for the antegrade percutaneous incision. Their series, which included two pelvic kidneys, reported a 78% success rate for the treatment of UPJO in congenitally abnormal kidneys [41]. Most of the published endopyelotomy series have involved an antegrade percutaneous approach, with some additional reports utilizing a retrograde ureteroscopic technique. A tapered endopyelotomy stent traversing the UPJ is recommended for 6 weeks [41, 42] (Figure 62.5). Oppenheimer and Hinman determined that 6 weeks of stenting was needed for regeneration of the muscular wall of the ureter [43]. An excretory urogram 1 month after stent removal is recommended to assess the patency of the UPJ. The advantages of endopyelotomy over open surgical repair include a shorter hospital stay and faster return to routine daily activities.

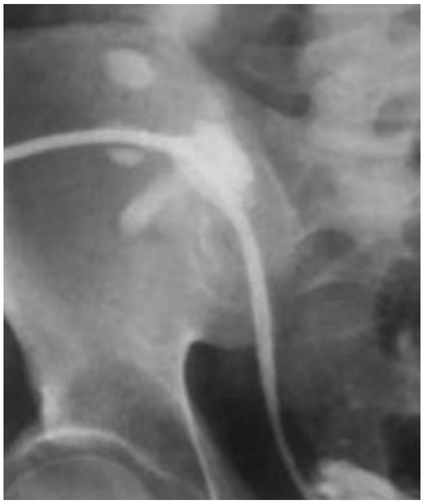

Figure 62.5 Nephroureteral stent placed after percutaneous endopyelotomy in a pelvic kidney.

Laparoscopic pyeloplasty

In 2004, Bove *et al*. reported three cases of laparoscopic pyeloplasty in pelvic kidneys with UPJO [44]. The laparoscopic approach provided good surgical exposure, and operative times were comparable to those of laparoscopic pyeloplasty in anatomically normal kidneys. The authors commented that laparoscopic pyelolithotomy can be performed concomitant with pyeloplasty when kidney stones are present.

Ureteroscopy

Although a percutaneous approach to the treatment of UPJO in the ectopic kidney is feasible, there is a risk of bleeding from injury to anomalous blood vessels or adjacent pelvic organs. Bales *et al.* suggest that ureteroscopic access may be advantageous in patients with a pelvic kidney, as it avoids percutaneous access [45]. Preoperative radiographic evaluation to determine the anatomy of the major vessels (angiography) and the location of surrounding organs is recommended, and intraoperative endoluminal ultrasonography may serve as a useful adjunct [46].

There are limitations to the ureteroscopic approach to UPJO in pelvic kidneys. Baba *et al*. employed a percutaneous approach in a patient with a pelvic kidney, UPJO, and a concomitant ureteral calculus [47]. Percutaneous transperitoneal endopyelotomy and transluminal antegrade ureteroplasty after ultrasonic lithotripsy were performed under laparoscopic guidance. A preoperative CT scan revealed tortuosity of the ureter with lateral rotation of the pelvic kidney and a dilated extrarenal pelvis. Preoperative pelvic angiography revealed hyperrotation (270°) of the pelvic kidney, with the main vascular pedicle passing dorsal to the kidney to reach the renal hilum. An attempt at ureteroscopy was aborted because of failure to pass the ureteroscope beyond the impacted stone. The stone was treated with ultrasound lithotripsy and forceps removal of the remaining fragments. After creation of the nephrostomy tract, a flexible nephroscope was used to inspect the narrowed UPJ, and a ureterotome was advanced over the working guidewire to incise the anterior wall of the obstruction. Serial twists of the ureter can occur in association with an ectopic kidney as a result of hyperrotation of the ureter. This rare situation creates a technical challenge in accessing pelvic kidneys and limits the utility of ureteroscopy in managing disease.

In a case report by Simone *et al*, one patient with a UPJO in a pelvic kidney underwent a laparoscopic endopyelotomy to treat the short obstructed ureter by tubularizing the redundant renal pelvis to create a neoureter. At 6-month postoperative follow-up, the patient remained with resolved hydronephrosis and demonstrated good renal function [48].

Laparoscopic pyelovesicostomy

Laparoscopic pyelovesicostomy was described by Davis and Wolf [49]. Following dissection of the prevesical space, a cystotomy was made equal to the length of the incision in the medial aspect of the dilated right renal pelvis. The vesicostomy was then sutured to the pyelotomy with a running absorbable suture. Pyelovesicostomy has been described as a management option for ureteral obstruction since 1973, but laparoscopic pyelovesicostomy is a recent approach [50]. Although there are advantages such as the relative technical ease with a short operative time and reduced blood loss, the disadvantages include a risk of bacterial cystitis progressing to pyelonephritis and the discomfort associated with a full bladder [47].

Extrarenal calyces are an uncommon congenital anomaly that may accompany ectopic kidney [51]. Extrarenal calyces can be associated with UPJO, with reports of obstruction in 22–37% of patients. In 2006, Wadhwa *et al*. described a unique laparoscopic approach to UPJO in a pelvic kidney associated with extrarenal calyces [52]. A window was created in the mesocolon to allow viewing of and access to the renal pelvis and the junction of the extrarenal calyces with the ureter. After dismembered pelvic reduction, the mesocolic incision was closed. This approach reportedly permitted excellent exposure of the anomalous renal anatomy and avoided the need to mobilize and translocate the sigmoid colon.

Conclusions

Although ectopic renal anomalies are not an infrequent finding, pelvic kidneys specifically are regarded as rare. While kidney stones and UPJO can be treated by minimally invasive techniques, the pelvic kidney requires additional treatment considerations because of the spatial orientation of the pelvis and the relation to surrounding organs, vessels, nerves, and bones. Stones in pelvic kidneys can be treated by ESWL, albeit with a greater need for retreatment or secondary procedures. Laparoscopy-guided percutaneous approaches also are effective in treating stones in a pelvic kidney and provide a safe means of establishing the tract. Given the altered and sometimes tortuous nature of the ureter in a pelvic kidney, ureteroscopy may have a limited role because of difficulty in passing instruments into the kidney. Ureteroscopic treatment of UPJO may be limited for the same reasons, and better results have been obtained with percutaneous endoscopic intervention. To date, multi-institutional large cohort studies involving comparative treatment of diseases in pelvic kidneys have been limited by the rarity of the anomaly. Additional studies are needed to compare the various treatments for disease of the pelvic kidney in order to decide which options have the most beneficial outcomes.

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CHAPTER 63

Management of Stone Disease in Renal Transplant Kidneys

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Introduction

Renal transplantation remains the optimal treatment for patients with endstage renal disease. It offers a longer survival and a better quality of life compared to dialysis. With the advances in immunosuppression and national transplant programs in many countries, including laparoscopic and hand-assisted laparoscopic surgery, renal transplantation is becoming increasingly common. The resulting improvement in graft and patient survival has led to the frequent presentation of the less common and the longer-term complications of transplantation. One such complication is urolithiasis in renal transplant patients. The incidence has been reported to be around 1% in successful transplants (range 0.3–3% in our review), and it is likely to increase as more transplants are performed and graft survival is prolonged [1, 2].

A calculus in a grafted kidney may develop *de novo* after transplantation, or may pre-exist in the allograft before transplantation, which is usually referred to as donor graft nephrolithiasis. There are various risk factors associated with transplantation patients that can lead to stone development, including metabolic disorders, infection, urinary stasis, and foreign body nidus. Some reports have suggested women outnumber men with this clinical entity [3, 4]. Stone disease puts transplant patients at greater risk for urinary tract obstruction, renal failure, and infection compared to the risk in the general population. Therefore, early diagnosis and proper management are essential for a successful outcome.

Historical perspective

One of the earliest reports of post-transplant urolithiasis was that of Hume *et al*. in 1966, who reported on a patient with a staghorn calculus associated with hyperthyroidism [5]. The stone regressed slightly after parathyroidectomy. Urolithiasis in graft kidneys has since been recognized as a complication of kidney transplantation. Dominguez *et al*. in 1970 reported on the occurrence of calcium phosphate stones in a renal allograft 2 months after transplantation. A parathyroid adenoma was noted and removed at the exploration of the neck [6]. In the same year, Latimer *et al*. reported calcium phosphate stones in the pelvis of a renal allograft 4 months after transplantation [7]. Their patient had both hyperparathyroidism and urinary tract infection (UTI) secondary to a ureterovesico-cutaneous fistula. There was no stone recurrence following parathyroidectomy and fistula repair. One year later, the development of nephrocalcinosis in renal transplants due to hypercalcemia and hyperparathyroidism was recorded with changes being observed microscopically as early as 4 weeks after transplantation [8]. Rosenberg *et al*. reported in 1975 on a patient who developed stones in the renal pelvis 4 months after transplantation [9]. Three major predisposing factors of nephrolithiasis found in the patient were hyperparathyroidism, UTI, and renal tubular acidosis. Parathyroidectomy was performed; however, surgical therapy for nephrolithiasis was deferred. In due course, she developed 17 “rejection

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episodes" with fever and serum creatinine elevations, and finally died from a febrile attack. With current knowledge, we believe that it would not be incorrect to assume that at least some of her "rejection" episodes were actually septic episodes associated with the underlying stone disease.

The initial report on donor graft lithiasis was made by Lerut *et al.* in 1979 [10]. They reported on a female patient who developed ureterohydronephrosis secondary to distal ureteral stenosis and an unsuspected calculus in an inferior calyx of the donor kidney. The ureter was reimplanted and a pyelolithotomy performed. More than 30 years ago these authors underlined the importance of inspection of the transplanted kidney to exclude the presence of a graft calculus. A second case of donor graft lithiasis was reported in 1984 [11]. The patient was diagnosed as having acute graft rejection until a stone causing ureteral obstruction was discovered. Bhadauria *et al.* was the first to describe the treatment [shock-wave lithotripsy (SWL)] after transplantation of a stone-bearing kidney [12]. A total of 34 cases of nephrolithiasis in living donor transplants were published up to 2008; 28 were known to harbor stones prior to transplantation [13].

Predisposing factors for stone disease in kidney transplant recipients

Metabolic disease, infection, immunosupression, ureteral obstruction (stricture), chronic urinary stasis (in a relatively horizontally lying kidney), foreign body nidus (nonabsorbable suture material), and donor graft lithiasis are accepted as the most common causes of stone formation complicating a transplantation.

Renal transplant patients who develop stones should undergo a metabolic evaluation to prevent future stone formation. The management of postrenal transplant hypercalcemia and hyperparathyroidism, and the role of parathyroidectomy have been thoroughly discussed in the literature. Parathyroidectomy can lower calcium level by decreasing the filtered load of calcium and by correcting or improving an associated renal tubular acidosis [9]. Steroids are often a part of immunosuppressive treatment, and may cause calcium reabsorption from the bones, resulting in hypercalciuria. Most stones in renal allografts have been reported to be calcium oxalate stones [14, 15]. In half of these patients, immunosupression with cyclosporine can produce hyperuricosuria, which may contribute to stone formation [16]. However, the role of hyperuricosuria and uric acid stone formation remains controversial with a reported incidence of uric acid stones in the range of 0.2–10% [4, 17, 18]. Guitard *et al*. reported a case of sulfadiazine-related obstructive urinary tract stone in a kidney transplant recipient [19]. Glicklich *et al.* reported the first case of 2, 8-dihydroxyadenine urolithiasis in a transplanted kidney [20].

Recurrent UTIs and the production of more concentrated alkaline urine have been held responsible for contributing to calculus formation in transplant patients [3, 18]. Urinary stasis is another factor that may have a role in stone development; a relatively horizontal kidney could potentially be associated with urinary stasis. Voiding dysfunction could also play a role in some patients and needs to be recognized and treated. Stricture at the ureteral anastomosis may ensue after anastomosis.

It has been speculated that the increased glomerular filtration rate and urine output on a per nephron basis that a transplanted kidney experiences may be sufficient to overcome any propensity the kidney may have for subsequent stone formation. However, this theory has not yet been proven [21].

Symptoms and signs

The most common presenting symptoms and signs are fever, septicemia, impairment of renal function, decreased urine output, anuria, and hematuria [3, 15, 22]. Typical renal or ureteral colic pain from acute hydronephrosis secondary to an obstructing stone in the transplant kidney is typically not present due to the severing of perinephric nerves during transplantation. Nevertheless, a minority of patients with a renal transplant report pain due to distention of the overlying fascia secondary to an enlarged, obstructed kidney [14, 23]. The presence of a stone in a transplant patient may cause a clinical presentation that may be easily mistaken for an acute rejection or acute tubular necrosis [11]. Delay in proper diagnosis may lead to loss of the graft; hence, intervention is warranted in most transplant patients who are found to have a stone [22]. Consequently, any patient presenting with unexplained fever and signs of graft rejection should be investigated with ultrasonography and noncontrast-enhanced computed tomography (CT) to exclude renal calculi [24] (Figure 63.1).

Stone disease as an inclusion/exclusion criteria for kidney donation

Kidney donation is a unique situation in which the individual undergoing the procedure has the potential for harm with no physical benefit [25]. Thus, it poses an ethical dilemma of how much risk is acceptable for a living donor [26]. Due to the organ donor shortage, some transplantation centers have relaxed their acceptance criteria for living kidney donation and allow what have been termed "complex living donors" [26]. Complex living donors are individuals with normal renal function at the time of evaluation who possess

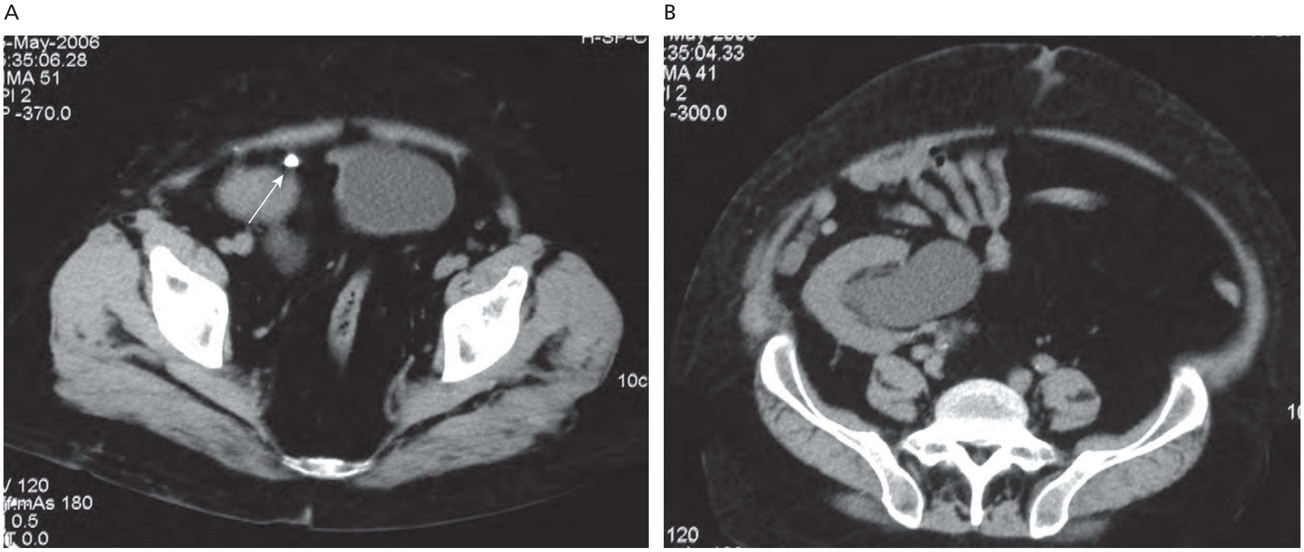

Figure 63.1 (A) CT image of an 8-mm upper ureteral stone in a transplanted kidney (arrow) (courtesy of Nejat Tansu MD). (B) Hydronephrosis due to the ureteral stone in the same patient (courtesy of Nejat Tansu MD).

potential risk factors for kidney disease in the future. A donor with nephrolithiasis is a complex donor [27]. The use of screening CT angiography has lead to an increased incidence of exclusionary radiographic findings in renal transplant donors [28]. Asymptomatic nephrolithiasis is one of the most common reasons for this increased exclusion rate [29].

The guidelines and consensus statements do not necessarily exclude living kidney donation in the context of urolithiasis. The general recommendation is to perform a risk stratification for donor and recipient with respect to stone composition, metabolic evaluation, the presence of single versus multiple stones, and the duration of stone-free episode. The US and UK guidelines consider current nephrolithiasis as a "relative contraindication" for kidney donation [30, 31]. They suggest taking stone composition into account; however, the criteria for inclusion or exclusion are not clear in the US guidelines. In the European Best Practice Guidelines, presence of multiple stones is the sole exclusion criteria irrespective of stone composition [32]. The more recent Amsterdam Consensus Conference states that stone bearers may donate the stone-bearing kidney if metabolic disorders and infections are excluded, and the stone is solitary, less than 1.5 cm in diameter, or potentially removable during transplantation (Table 63.1) [33]. The size threshold of 1.5 cm stems from a consensus decision rather than scientific evidence [33]. *Ex vivo* ureteroscopy (ExURS) during transplantation is suggested as a feasible means of stone treatment for these donors.

The results of a survey conducted in the USA reflect a temporal trend toward increased acceptance of donors

Table 63.1 Potentially suitable donors as recommended by the Amsterdam Consensus Conference on the Living Donor (adapted from Delmonico [33]).

Potentially suitable donors

1. Asymptomatic potential donor with *history of single stone* if:
    - No hypercalciuria/hyperuricemia/cystinuria/hyperoxaluria
    - No metabolic acidosis
    - No urinary tract infection
    - No multiple stones or nephrocalcinosis (CT scan)
2. Asymptomatic potential donor with *current single stone* if:
    - Donor meets criteria under 1
    - Current stone size < 1.5 cm or potentially removable during transplant

Stone formers who should not donate

Nephrocalcinosis on X-ray

Bilateral stone disease

Stone recurrence while on appropriate treatment (failed therapy)

Stone types difficult to prevent/with high recurrence:
- Cystine stones
- Struvite stones

Stones associated with inherited or other systemic disorders:
- Primary or enteric hyperoxaluria/distal renal tubular acidosis/sarcoid
- Stones in the setting of inflammatory bowel disease

with a history of kidney stones, both in attitude and in practice [27]. The great majority (77%) of responding centers allowed stone formers to donate. More than one-third (37%) of centers reported a change in their attitude towards accepting donors with a history of kidney stones over the last 5–10 years or with current stones. There is no formal donor registry in the USA following stone-bearing donors over time [34]. History of or present urolithiasis in a potential kidney donor requires a thorough work-up, as suggested by international guidelines, since stone disease may recur both in the transplant and in the remnant donor kidney [35]. The highly sensitive CT screening of kidney donors and the acceptance of donor candidates with incidental stones merit the analysis of stone-related complications in donors and recipients. In the absence of data, physician practices are probably based on trends of need rather than published patient outcomes or evidence-based guidelines [27].

While the Amsterdam Consensus Statement and the European Best Practice Guidelines do not make any recommendations regarding the necessity of a stone-free episode, the UK and the US guidelines advocate a 10-year stone-free period prior to kidney donation [30, 31, 33, 35]. In a survey conducted in Germany, only one center was in favor of complying with the 10-year rule [13]. In their evaluation of this survey, Giessing *et al.* proposed a 2-year stone-free period to be satisfactory if metabolic and infectious disorders were excluded [13].

Identification and exclusion of a metabolic or infectious stone disease and stone composition are at least as important as stone size. Nevertheless, the obstacles associated with identifying stone composition without removing the stone are well-known to all urologists. The Amsterdam Consensus Statement and the UK guidelines exclude donors with a history of cystine and struvite stones, while the US guidelines describe the high recurrence rate of these stones without offering specific recommendations [30, 31, 33]. The European Best Practice Guidelines fail to make any suggestions on the relevance of stone composition [32]. Potential donors with a history of uric acid or calcium phosphate stones and a normal metabolic work-up would not be excluded according to the Amsterdam Consensus Conference [33]. In contrast, the UK guidelines exclude these donors, while the US guidelines fail to make strict recommendations [30, 31]. As for calcium oxalate stones, the Amsterdam Consensus Conference advocates exclusion of these potential donors if the stones are due to a hereditary condition, e.g. primary or enteric hyperoxaluria, distal renal tubular acidosis, or inflammatory bowel disease [33]. The British guidelines mention the high recurrence rate of oxalate stones, suggesting taking caution; but they accept these donors if their metabolic work-up is normal [30].

A survey questioning the attitude to nephrolithiasis in potential living kidney donors in Germany revealed interesting results: Nephrolithiasis at the time of transplantation was an exclusion criterion at 36% of the German centers [13]. A history of stone disease did not preclude living kidney donation. The length of stone-free episode was regarded as relevant by 42% of all centers. Stone composition was a criterion for 54%. Less than half of the centers excluded donors with cystine stones and only two centers excluded donors with struvite nephrolithiasis. Giessing *et al* concluded that the recommendations were mostly disregarded among the surveyed centers, and they speculated that it might suggest a lack of awareness of the risks associated with nephrolithiasis in the context of living donor kidney transplantation [13]. Another similar survey performed in France revealed that half of French kidney transplant centers refuse living kidney donation when the donor has a history of stone disease, even in the absence of present urolithiasis [36].

Management of a "complex donor" with stone disease

The Amsterdam Consensus Statement references only one of eight studies available at the time of its publication [13]. More studies have been published on the retrieval of a stone-bearing kidney and its management before, in the course of, or after transplantation. Bhaduria *et al.* performed SWL after live donor transplantation; Yigit *et al.* treated two donors with SWL prior to donation and performed bench pyelotomy in another prior to transplantation [12, 37]. Rashid *et al.* performed back-table ureteroscopic stone removal [38]. Recurrence of stone disease was not detected in these three series with nearly 3-year follow-up. Devasia *et al.* performed SWL in a living donor with a 12-mm upper calyceal stone before transplantation [39]. Three kidneys were transplanted with known 4-mm stone fragments and all had an uncomplicated course [39]. Kumar *et al.* managed one of six live donors with a pelvic stone with bench pyelolithotomy and the remaining five with SWL after transplantation [40]. In two donors, they removed ureteral stones after kidney retrieval. Recipients remained free of stone recurrence or functional deficit. They reported a complication of obstructive recurrent stone disease development 2 years after transplantation in a patient requiring emergency stenting and ureteroscopic stone extraction.

Klinger *et al*. suggested using ultrasound routinely in the operating room in parallel with transplantation, so that ischemia time would not be influenced [4]. All nine stones in the allografts in their series would have been detected if ultrasonography had been performed. The authors stated that stones diagnosed prior to or during transplantation can be easily removed during the procedure, and do not jeopardize transplantation results, thus reducing postoperative morbidity and costs. On the other hand, the morbidity of allograft stones diagnosed immediately after transplantation may be high, as renal function is variable; any ureteral obstruction requires immediate intervention. Of the five patients they transplanted with stones, four (80%) developed complications [4]. Three needed an emergency nephrostomy, with one patient having permanent renal impairment and another requiring ureteral reimplantation. Therefore, their conclusion was that treatment of these stones cannot be delayed and immediate stone removal is needed. Capocasale *et al*. suggested not treating calyceal stones at the time of bench surgery due to increased risk of urinary leak from the pyelolithotomy suture line and the availability of less invasive endourologic procedures after transplantation [41]. However, they were in favor of removing ureteral stones.

Ex vivo ureteroscopy

The Amsterdam Consensus Conference suggests ExURS during transplantation as a feasible means of stone treatment for donors with urolithiasis [33]. ExURS may be easier to perform compared to *in vivo* ureteroscopy, since the removed kidney no longer exhibits the normal anatomic narrowing of the ureter at the iliac vessels and the ureterovesical junction [21]. In addition, the kidney can be manipulated to vary the ureteropelvic angle to facilitate access to all calyces. The average additional cold ischemia for the ExURS is below 10 min, well within the period accepted to be safe for subsequent transplantation [21].

Rashid *et al*. reported the largest experience with ExURS during transplantation [21]. Immediately after kidney explantation, the kidney was flushed and prepared for transplantation in the usual fashion, and then placed in sterile, iced preservation solution. Dilation of the ureter was performed in only one case. Ureteroscopy was performed using a 6.9F semi-rigid ureteroscope. The kidney and ureter were kept cold throughout the ExURS by immersion in an iced saline bath. All stones were localized under direct vision in comparison with previous CT, except in the first patient in whom fluoroscopy was used. Stone burden was treated with holmium laser lithotripsy or endoscopic basketing. Upon completion of the ExURS procedure, the kidney was transplanted. A stent was placed at ureteral implantation when deemed necessary to aid passage of stone fragments, or if there were concerns for ureteral trauma and subsequent edema potentially leading to obstruction.

The procedure was not only technically feasible, but also almost uniformly effective in that all but one stone was successfully treated and/or removed, and all kidneys were rendered stone free. Stone recurrence was observed in neither the recipients nor the donors. There were no instances of post-transplant ureteral anastomotic leak or stricture. Care was taken to minimize handling the ureter and the smallest diameter scope available was used. Routine dilation of the ureter was not necessary when using a 6.9F semi-rigid instrument. The semi-rigid ureteroscope was preferred due to its superior optics, shorter length, and subsequent ease of use. Negotiating the scope in all calyces was facilitated by rotating the kidney, so that the desired calyx was inline with the ureteral axis. A minimal amount of pressure irrigation was used to minimize the potential risk of pyelovenous, pyelotubular, or pyelolymphatic reflux.

In a small series, Triverdi *et al*. reported on two patients managed with ExURS [42]. An 8.5F semi-rigid ureteroscope was used without ureteral dilation. The kidney was cooled throughout the procedure in an iced saline bath, stones were fragmented with pneumatic energy, and fragments were retrieved with forceps. Uretereoneocystostomy was performed over a double-J stent. Renal function was not adversely influenced by the intervention.

Thus, patients who are acceptable kidney donors and harbor incidental, unilateral, nonobstructive nephrolithiasis can safely donate and effectively have the stone burden treated by ExURS with or without holmium laser lithotripsy at transplantation. This method is technically feasible, has no apparent effect on allograft function, and is not compromised by ureteral complications and *de novo* stone formation.

Importantly, a donor with current stone disease must be informed about a potentially increased risk for themselves and the recipient. Donors must realize the importance of careful monitoring and express a commitment to practicing avoidance measures for stone recurrence. Likewise, recipients must be thoroughly informed of the potential for stone-related complications in an allograft with a stone left *in situ*. The recipient must weigh the risk of an obstructing stone that might result in delayed recognition of graft failure against the risk of a shorter lifespan and increased cardiovascular morbidity associated with renal failure without transplantation [29]. Fully informed consent and life-long close follow-up is explicitly advocated only in the UK guidelines, but must be the standard procedure in the context of nephrolithiasis in living kidney donors [13, 30].

Treatment of stone disease in a graft kidney

The treatment of *de novo* stones in transplanted kidneys follows regular stone management guidelines for single kidneys in general. Since transplant patients depend on their solitary kidney for renal function, calculi should be treated aggressively to minimize the possibility of obstruction and loss of graft function. The management of these patients is complex because of their immunosuppressive status, borderline renal function, and an altered renal innervation that masks the typical presenting symptoms [16]. Management options include close monitoring, SWL, ureteroscopy, percutaneous nephrolithotomy (PCNL), and open surgery when all else fails. There are no data on the laparoscopic treatment of stone disease in grafted kidneys.

Active surveillance

Monitoring renal calculi in the patient with a transplant is not ideal, although in certain situations it can be performed [15, 16, 41]. In patients with small stones of 4 mm or smaller and no signs of impaired allograft function, a watchful waiting approach is justified. The common medications used for metaphylaxis may not be tolerated by transplant patients, e.g. the potassium load from potassium citrate or the sodium load from sodium bicarbonate. Close monitoring with weekly serum creatinine levels and renal ultrasound is mandatory, but has its pitfalls. Renal ultrasonography alone may be unreliable in detecting moderate obstruction, because dilation in the collecting system is not pathognomonic. Moreover, the anatomic variation of the allograft position may overestimate the degree of hydronephrosis. The only definite signs of an arising problem are decreased urine production despite sufficient fluid intake and an increase in serum creatinine. It should always be recognized that since the kidney is denervated, typical pain or renal colic is not to be expected. As with active surveillance in any other disease, compliance of the patient must be excellent for a conservative approach to work.

Shock-wave lithotripsy

SWL is often a reasonable initial treatment for stones smaller than 1.5 cm in diameter [3]. However, there are some limitations for routine utilization of SWL. The overlying bony pelvis might preclude adequate localization of the transplanted kidney and also can cause shock-wave attenuation, decreasing SWL efficacy [14]. Patients are usually treated in the prone position to better visualize the stone. It is often required to place a concurrent percutaneous nephrostomy tube in an acutely ill patient [15] (Figure 63.2). The development of steinstrasse may cause obstruction and risk kidney function.

Some groups have reported success with SWL in this patient cohort [3, 4]. Challacombe *et al*. observed treatment success in 13 patients in whom stones with a mean size of 8.1 mm were treated with SWL [3]. Although seven of the 13 patients required multiple SWL treatments, the investigators concluded that SWL is an acceptable treatment alternative for stones of less than 1.5 cm in the allograft kidney. Others have reported difficulty with SWL localization of the allograft and the stone because of the complex bone structures in the pelvis [12]. The group from the University of Vienna stated that with increasing experience, they would be more restrictive in placing nephrostomy tubes during SWL treatment [4]. They further suggested close monitoring of steinstrasse to be sufficient unless infection and/or oliguria were present and providing the overall stone burden was low.

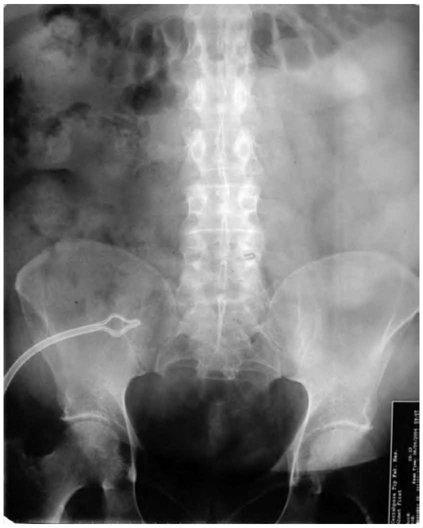

Figure 63.2 Kidney, ureter, and bladder (KUB) image of a patient who was rendered stone free after two shock-wave lithotripsy treatment sessions. A nephrostomy tube was placed in the transplanted kidney due to anuria initially, and was not removed until after treatment (courtesy of Nejat Tansu MD).

Ureteroscopy

Retrograde access to a transplanted kidney is typically difficult owing to the anterior location of the ureteral anastomosis and thus, ureteroscopy is not an easy option for stone management in these patients [24]. Nevertheless, it could be an initial option for ureteral stones or performed after failed SWL [22]. It is essential to determine the location of the orifice and whether the distal native ureter was used. Flexible instruments with active secondary deflection are particularly useful in reaching calculi in transplanted kidneys [3].

Percutaneous nephrolithotomy

Renal stone extraction through a percutaneous access was initially reported by Fischer *et al*. in 1982 [43]. They

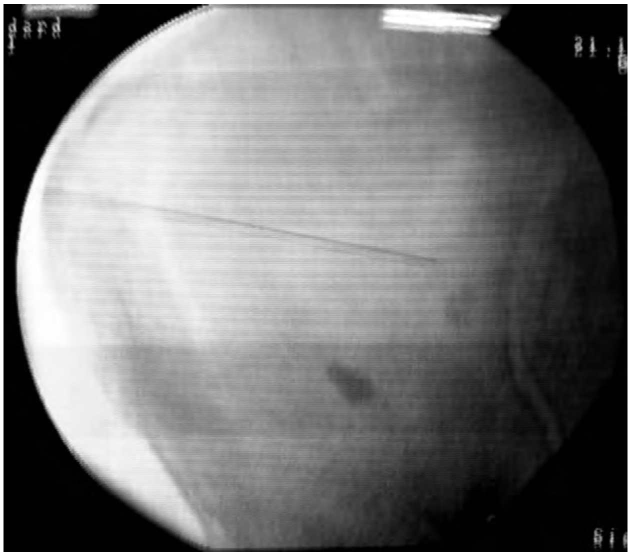

Figure 63.3 Fluoroscopic imaging of two stones in a transplanted kidney. The stones are located in the renal pelvis and lower calyx. The collecting system has been punctured with a Chiba needle (courtesy of Ali Ulvi Onder MD).

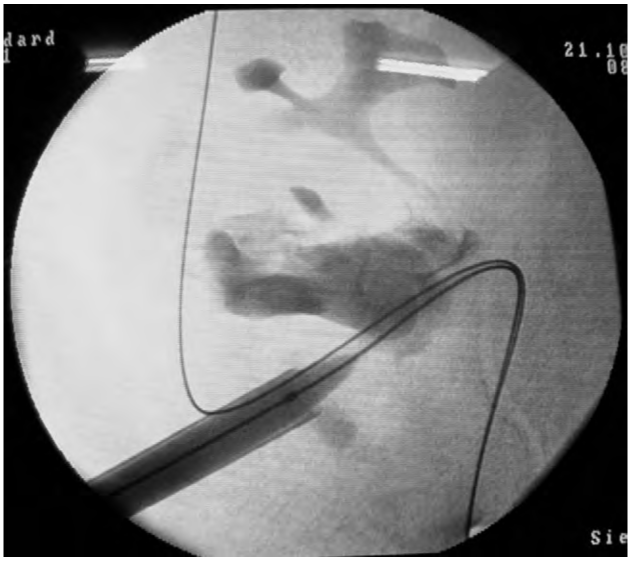

Figure 63.4 Percutaneous nephrolithotomy in a patient with a transplanted kidney. The tract is dilated with an Amplatz balloon and an Amplatz sheath is introduced (courtesy of Ali Ulvi Onder MD).

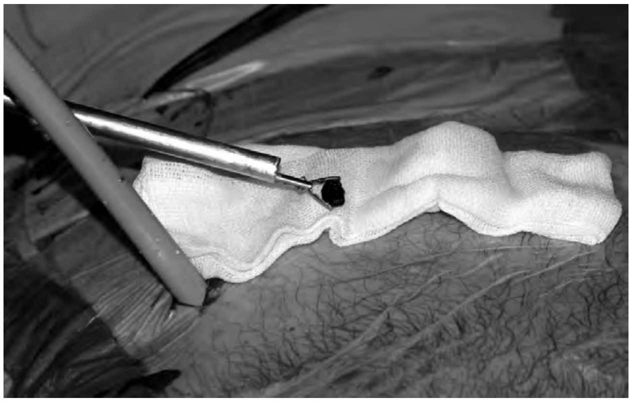

Figure 63.5 Percutaneous nephrolithotomy is performed in a supine position in patients with transplanted kidneys. A transplanted kidney is often accessed easily because of its close proximity to the skin. Note that the Amplatz sheath is located mostly outside of the body, due to the short distance between the skin and the graft (courtesy of Ali Ulvi Onder MD).

removed a uric acid stone through a nephrostomy tract with the aid of a basket catheter after using chemolysis. PCNL of a renal stone from a transplanted kidney was first described by Hulbert *et al*. in 1985 [44]. Initial publications of case reports were followed by a few series [3, 16, 22, 24, 45]. It is currently the state-of-the-art recommendation for stones larger than 1.5–2 cm. in diameter in transplanted kidneys [16].

The technique differs somewhat from that for a normally located kidney. Obtaining a preoperative CT scan to exclude overlying bowel and aid in planning appropriate percutaneous access is advisable [16]. Ultrasound guidance is recommended to aid in direct calyceal puncture and to avoid potential injury to the bowel [15]. Percutaneous access with fluoroscopy alone is not easy, because of the difficulty in opacifying the collecting system using a retrograde approach [16] (Figure 63.3). In the presence of a complex anatomy around the graft, CT-guided access might be the safest modality [16].

PCNL in normal kidneys is typically performed with an access into the posterior calyx with the patient in the prone position. In contrast, percutaneous access into a transplanted kidney is done with the patient in the supine position and into an anterior calyx. This is due to the anterior location of the transplanted kidney in the true pelvis, along with the change in the axis of the kidney.

Since the diagnosis is usually made by ultrasonography, an interventional radiologist will usually have already placed a nephrostomy tube to relieve the obstruction. Therefore, the patient will present to the urologist with a nephrostomy tube in place. The access is the key to any PCNL; therefore, if the pre-existing nephrostomy tract is not ideal, the urologist should not hesitate to perform another puncture in another location in order to facilitate surgery and prevent kidney damage [16].

The transplanted kidney is often accessed easily because of its close proximity to the skin (Figures 63.4 and 63.5) The dense scarring surrounding the kidney may be a nuisance for tract dilation. If balloon dilation fails initially, Rifaioglu *et al.* recommend another attempt after the balloon is stiffened by placing it in ice slush [16]. In cases when balloon dilation fails, Amplatz dilators or metal Alken sequential dilators may be used. In patients who have undergone previous open or percutaneous surgery, the use of a fascial incising needle, which provides a 4.5-mm diameter fascial opening, may be helpful for balloon dilation [46]. Flexible instruments may be necessary during PCNL owing to the orientation of the transplanted kidney. Rifaioglu *et al*. used a combination of ultrasonic lithotripsy with the rigid nephroscope, and holmium:YAG laser lithotripsy with the flexible endoscope (cystoscope and ureteroscope) [16]. All patients who underwent PCNL had a nephrostomy tube left in place and underwent antegrade pyelography to demonstrate free drainage and stone-free status before tube removal.

A total of 15 patients underwent successful PCNL in a transplanted kidney at the University of California in San Francisco, USA [16]. In all but three patients, access into an anterior upper calyx was achieved, and access was obtained with ultrasound guidance alone or a combination of ultrasound guidance and fluoroscopy. Ten patients had a pre-existing nephrostomy tube, and this was used in all but one patient. Of the 15 patients, eight (53%) were treated with percutaneous flexible nephroscopy/ureteroscopy, and seven had tracts dilated to 30F in order to perform rigid PCNL. All patients were rendered stone free at the end of the procedure without any complications.

He *et al*. described a modified PCNL technique using a miniature endoscope through a small access tract in seven patients [45]. The stone size was between 5 and 45 mm, and all patients were reported to be stone free and free of complications.

Krambeck *et al*. reported on 13 patients with a renal transplant who underwent PCNL [14]. The primary presenting complaint in this cohort was acute renal failure, followed by hematuria, UTI, and pain. Average stone size was 1.36 cm. CT of the pelvis was performed routinely before the procedure. Collecting system access was achieved under ultrasound and fluoroscopic guidance by interventional radiology, which was later dilated to 28F using Amplatz fascial dilators. A single access tract was used in 12, and two tracts were used in one patient. A rigid nephroscope was mainly used; however, flexible instruments were also used to access obscure calyces when necessary. The majority of the patients (77%) were stone free 24 h after the procedure, based on an evaluation with a nephrostogram. Repeat endoscopy was required in three patients to achieve subsequent stone-free status. Postoperative complications developed in three patients, including sepsis, gastrointestinal bleeding, and herpes esophagitis. A single stone recurrence was observed in one patient and treated with SWL at a mean follow-up of 5.3 years. One patient who presented with renal failure prior to stone treatment went on to require a second transplant.

Open surgery

Open surgical approaches should be reserved for patients who fail one of the less invasive procedures. Delayed wound healing and infectious sequelae are potential complications of open surgery in these immunosuppressed patients. In addition, an open surgical approach to the renal pelvis can be technically difficult due to scar tissue, and thus should be reserved for patients who fail PCNL [47].

Conclusions

Transplant urolithiasis requires renal physicians and urologists to maintain vigilance and a high index of suspicion. It is best managed in centers that are well equipped and have expertise to offer the appropriate treatment/intervention. Preferably, there should be access to an on-site lithotripsy machine, flexible ureterorenoscopes with holmium laser, and urologists with significant experience in PCNL. Most patients with calculi of less than 1.5 cm can be rendered stone free with SWL. If this fails, flexible ureterorenoscopy and holmium laser fragmentation may be attempted. For larger stones, PCNL gives the best chance of complete stone clearance.

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CHAPTER 64

Stones in Urinary Diversions: Causes and Treatment

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Introduction

The 19th century saw the initial description of the use of the intestine in urinary diversions by John Simon in 1852. In the early 20th century many techniques for this were described; however, success rates were poor and complication rates were high, resulting in their limited application. Improvements in surgical techniques and instrumentation, together with antibiotics and pharmacologic advances, helped to broaden the application of these techniques. Ureterosigmoidostomies are the oldest form of urinary diversion. While it has waned in popularity due to the significant long-term complications, especially related to *de novo* malignancies, it still remains a viable option for a select group of patients. By the 1950s the ileal conduit, as described by Bricker, became the most commonly used form of urinary diversion today. Currently, there is a wide variety of diversion types available to patients requiring urinary diversion.

While most patients with a urinary diversion can expect long-term functionality with minimal morbidity from their diversion, they are not without long-term complications. Most patients with diversions are at increased risk of chronic renal deterioration and urinary tract infection. Common late complications include stomal stenosis, stones in the reservoir, increased stone incidence in the upper tracts, catheterizing difficulties, incontinence in continent reservoirs, and stenosis of the ureterointestinal anastomosis.

Several modifications and advances have been aimed at decreasing the rates of these complications; however, there remains a significant incidence. Often, the most vexing is the increased risk of stone formation in either the reservoir itself or the upper urinary tract. Reducing the incidence and morbidity of these complications with preventive medical management or surgical techniques remains a challenge.

Stone composition

Most stones formed in patients with urinary–intestinal diversions are composed of magnesium and ammonium phosphate. In addition to struvite stones, calcium oxalate, carbonate apatite, calcium phosphate, and ammonium hydrogen urate stones have been reported [1]. Risk factors for urolithiasis include the presence of foreign materials, particularly staples, retained intestinal mucus, chronic colonization of the reservoir with bacteria [2], infection with urease-producing bacteria, as well as increased renal excretion of phosphate, calcium, sulfate, magnesium, and hypocitraturia [3].

Bacteriology

The majority of patients with urinary diversions are colonized with bacteria. Most are colonized with multiple organisms, some of which are uropathogenic. Suriano *et al*. reported on 119 urine cultures taken from the 40 patients with orthotopic ileal neobladders and found a 57% rate of positive cultures: Gram-negative organisms such as *Escherichia coli*, *Proteus mirabilis*,

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Citrobacter koseri, and *Kluyvera ascorbata*, as well as the Gram-positive colonizers *Enterococcus faecium, Entrococcus faecalis, Streptococcus mitis*, Group G beta-hemolytic streptococcus, *Enterococcus casseliflavus*, *Staphylococcus aureus*, and *Gemella morbillorum.* Of these, the most prevalent organisms were *E coli, E. feacalis, E. faecium,* and *Proteus mirabilis* [4]. In ileal and colon conduits, the rates ranged from 14% to as high as 96%. It bears mentioning that not all these patients became symptomatic from the colonizing bacteria [5–8]. Typical colonizing bacteria for conduits were predominated by skin flora such as *Streptococcus spp* and *Staphylococcus epidermitis*, though uropathogenic flora were also seen.

Incidence

Stone formation is reported to occur at a rate of 3–11% in patients with the Indiana pouch. This is attributable to the absence of nonabsorbable foreign materials in its construction. This rate increases however with longer follow-up. Terai *et al.* attributed this increased rate to metabolic factors as well as decreased oral fluid intake [1, 3]. The incidence of renal stone formation ranges between 16.7% and 26.5% with the Kock pouch. This is often attributed to exposed staples or nonabsorbable sutures in the reconstructed urinary tract. A rate of 9.8% was reported with the Mainz pouch [9, 10]. The Florida pouch, at a mean follow-up of 6.3 years, had a 15% incidence of stone formation [2]. With a shorter follow-up, the incidence of urinary calculi in hemi-Kock neobladder and Hautmann ileal neobladder was 2.1% and 2.7%, respectively [10, 11]. The introduction where possible of absorbable staples and sutures removes any potential nidus for stone formation [2].

Risk factors for stone formation

Continent reservoirs are at risk for stone formation within the pouch. Risk factors include residual urine, bacterial colonization, and foreign bodies such as metal staples in contact with urine, hypercalciuria, and hypocitraturia. The presenting signs are varied and can include hematuria, infection, sepsis, and obstruction, with reservoir perforation or rupture occurring in very rare cases.

Stones may be characterized as infectious or metabolic but are usually a combination of the two, coupled with a foreign body acting as a nidus. Stones will ultimately recur unless the nidus, usually exposed staples or nonabsorbable sutures, is removed at the time of stone removal [12]. In the study by Terai *et al*. comparing the Indiana and Kock pouches, the authors demonstrated no clear relationship between urinary bacteriology and calculus formation. The infection stones in their study had been formed on foreign bodies and the predominating infectious organisms were urease-producing organisms such as *Proteus spp* and *Providencia spp* [13]. The authors also noted that a small but significant portion of stones were purely metabolic. Long-term increases in urinary calcium, phosphate, and magnesium concentrations, as expected after diversion, were thought to be contributing causes. Increased risk of calcium oxalate formation is not expected secondary to a urinary diversion; therefore, these groups of patients were already predisposed to stone formation unrelated to urinary diversion [3]. However, it is known that diversions utilizing long segments of ileum can induce enteric hyperoxaluria [14].

Struvite stones, reflux, and mucus

Most urinary diversions are constructed without regard to reflux in adult patients. Free reflux of urine from the reservoir or conduit into the upper tracts is a common finding. This reflux of urine allows the colonization of the upper tracts with urea-splitting organisms such as *Proteus spp, Klebsiella spp, Pseudomonas spp, Staphylococcus spp, Providencia spp, Ureaplasma urealyticum, Citrobacter freundii, Enterococcus spp,* and *Streptococcus spp*. These organisms all produce urease which hydrolyzes urea into ammonium and hydroxyl ions, i.e. the breakdown of urea and water into ammonium and bicarbonate ions. The bicarbonate ions raise the pH of the urine.

In the presence of alkaline urine ($pH > 7.2$), the abundant ammonium ions and phosphate ions result in precipitation of magnesium ammonium phosphate crystals ($MgNH_4\ PO_4 \bullet 6H_2O$) and carbonate apatite ($Ca_{10}\ (PO_4)\ 6 \bullet CO_3$) crystals, so-called struvite stones. These stones are often also composed of a core or interspersed layers of matrix from mucoproteins that refluxed from the conduit.

Hyperchloremic metabolic acidosis is a common finding in patients with urinary diversions, particularly when ileal and colonic segments are used in the construction of the urinary reservoir. The prolonged contact of urine with the bowel segment leads to exchange of bicarbonate and chloride ions, such that a serum acidosis results from an excess of hydrogen ions in the serum. The acidemic state results in impaired reabsorption of calcium from the proximal tubules and decreased renal production of citrate. Additionally, increased reabsorption of citrate from the urine by the exposed intestinal segments may be present. The resulting hypercalciuria, hypocitraturia, alkaline urine, and urinary abundance of ammonium and phosphate ions all favor stone formation.

Oxalate stones

Loss of ileum results in varying degrees of intestinal malabsorption. This condition is commonly seen in patients after resection of ileum for colon cancer or inflammatory bowel diseases such as Crohn's ileitis. In patients with urinary diversions, the length of ileum resected is directly correlated with the postoperative risk of stone formation, with patients having longer segments resected being more prone to stone formation. The fatty acids and bile salts that are normally absorbed in the ileum pass into the colon where they undergo saponification by binding with calcium. With less calcium available to bind oxalate in the intestines, there is an abundance of free ionized oxalate, which is readily absorbed by the intestines and excreted by the kidneys. This leads to hyperoxaluria which in turn leads to increased kidney stone formation.

Urate stones

If chronic diarrheal states result after using a bowel segment for urinary diversion, hyperuricemia and hyperuricosuria can develop. Often, however, the cause of the hyperuricosuric state is unknown in the absence of overindulgence of purine-rich foods.

Surgical management

Conservative management with observation for spontaneous passage, extracorporeal shock-wave lithotripsy (ESWL), antegrade and retrograde ureteroscopic manipulation, percutaneous nephrolithotomy (PCNL), and percutaneous or transstomal reservoir or conduit lithotripsy, are all management options available for treating patients with urinary diversions. The management approach chosen depends on the location, stone size, patient's reconstructed anatomy, and underlying cause of the stone. Historically, open surgical extraction was the only option for managing stones in diversions. However, newer minimally invasive techniques coupled with advances in endosurgical tools have made open surgery a very rare necessity. With these new advances came decreased morbidity, length of hospitalization, and faster recovery (see Video 64.1).

In cases where there is no ureteral reflux from the reservoir into the upper tracts, percutaneous access can be challenging. In this scenario, ultrasound guidance is necessary to locate the kidney for initial access. Under ultrasound guidance access can be obtained into the collecting system, allowing an antegrade nephrostogram to be performed, and then a more optimal access location can be obtained in the usual manner using fluoroscopy. Alternatively, anatomic landmarks can be used to gain initial blind access into the renal pelvis. Again, once access is obtained into the collecting system, a nephrostogram can be performed, and the optimal calyx for percutaneous nephrolithotomy can then be chosen under fluoroscopic guidance.

When ureteral stones are located along the approach to the conduit or reservoir, especially the segment of the left ureter that is tunneled under the root of the mesentery (see Figure 64.3), maneuvering and maintaining the flexible ureteroscope into an optimal and favorable position can be especially challenging. In a similar fashion, stone basketing is also often challenging in this location. The more flexible stone baskets, such as nitinol baskets, are often the best choice since they do not interfere as much with the deflectability of the ureteroscope as other stiffer baskets. At other times, however, a stiffer basket may be necessary to allow for greater pulling force while entrapping the stone; this can often be useful for stones that are embedded within the wall of the ureter.

Once stone clearance is completed, it is important to inspect and evaluate the ureteroileal anastomosis, and to perform a biopsy as needed to check for recurrence of tumor. Often, however, stricture and stenosis are found, and these need to be addressed. In the absence of tumor recurrence, a combination of dilation and incision can often yield good results and maintain patency of the anastomosis.

Stones in the kidney and ureter

For the most part, upper tract calculi in patients with urinary diversions can be managed similarly to patients without diversions, with certain special considerations. The major consideration involves the optimal approach to the ureter. Initial management for most calculi in patients with urinary diversions includes observation for spontaneous passage, ESWL, antegrade or retrograde ureteroscopic lithotripsy, PCNL, and trans-stomal or percutaneous pouch lithotripsy. For diversions with narrow-lumen stoma, such as the Mitrofanoff valve or Indiana pouch, manipulation through a transstomal approach may result in a stricture and difficulty with catheterizations, or in loss of the continence mechanism.

Incontinent diversions (Figures 64.1–64.3)

Loop diversions are the most commonly performed incontinent diversions. The surgical technique for their construction has not changed since their introduction. Ileal segments are most commonly used, although other bowel segments such as transverse and sigmoid colon and, less commonly, jejunum have been used. Metabolic consequences are similar for these segments, with the exception of jejunal segments. Stone formation within the loops are mostly due to passage from the upper tracts, presence of a foreign body such as exposed staples and sutures, residual urine, or stomal stenosis [15, 16].

To adequately address stones passing from the upper tract, detailed knowledge of each patient's unique

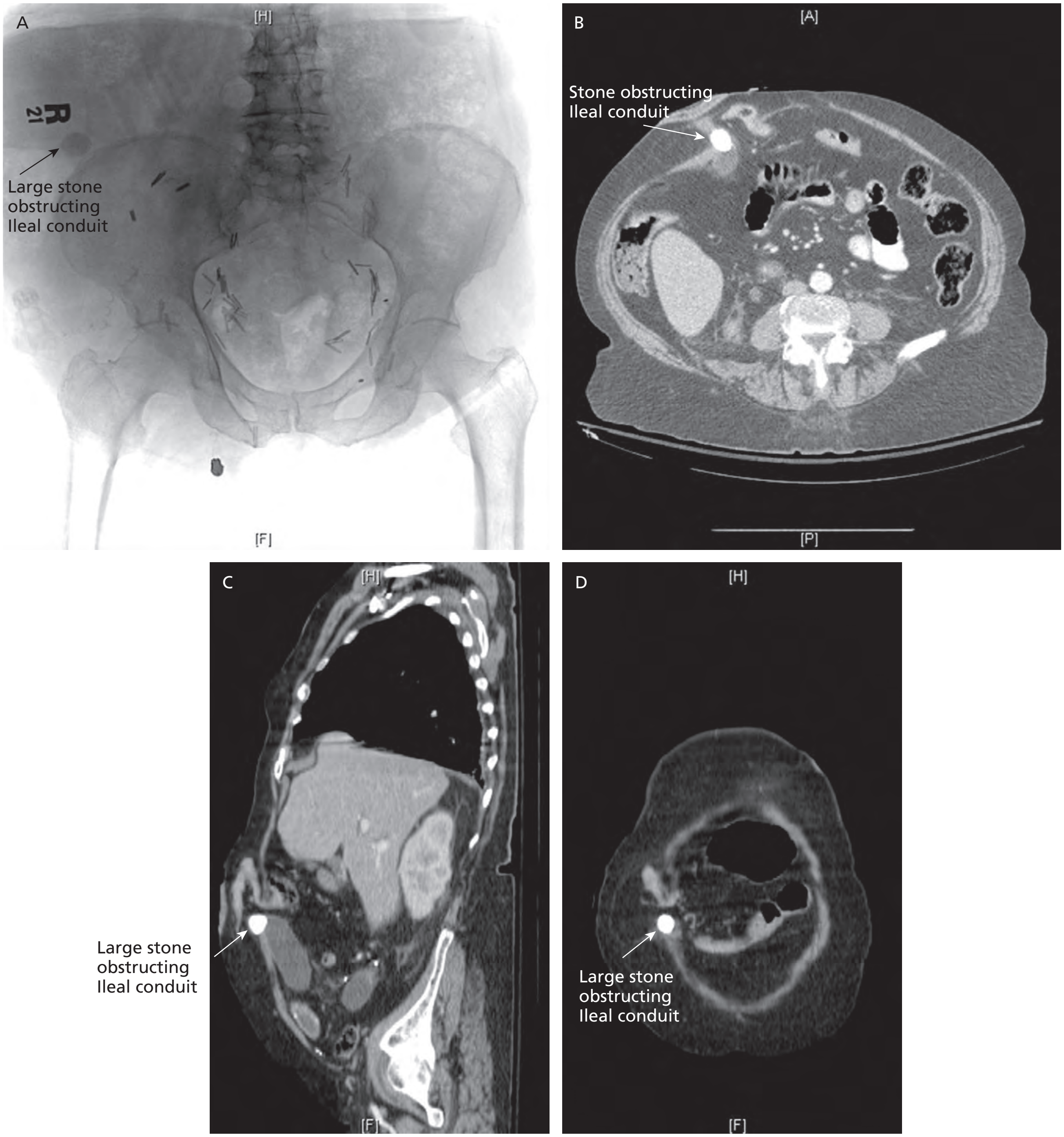
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Figure 64.1 Large stone completely obstructing ileal conduit. (A) Anteroposterior view; (B) axial view; (C) sagittal view; (D) coronal view.

reconstructed anatomy is crucial. Contrast-enhanced CT with delayed imaging is useful. ESWL is a good initial treatment for small upper tract stones. Also, a renal scan may be useful in assessing for obstruction at the ureterointestinal anastomosis. If the anastomosis is patent, a retrograde approach can be used to address upper tract stones. Placement of a ureteral access sheath and super-stiff guidewires can aid in retrograde passage of instruments, especially in very redundant loops. Percutaneous access may be necessary for antegrade placement of guidewires, followed by retrograde techniques. For stones within the loop or close to the ureterointestinal anastomosis, the foreign body nidus needs to be removed as well after stone removal. Stomal stenosis, if not addressed, can lead to upper tract deterioration, increased residual urine, and possible perforation of the

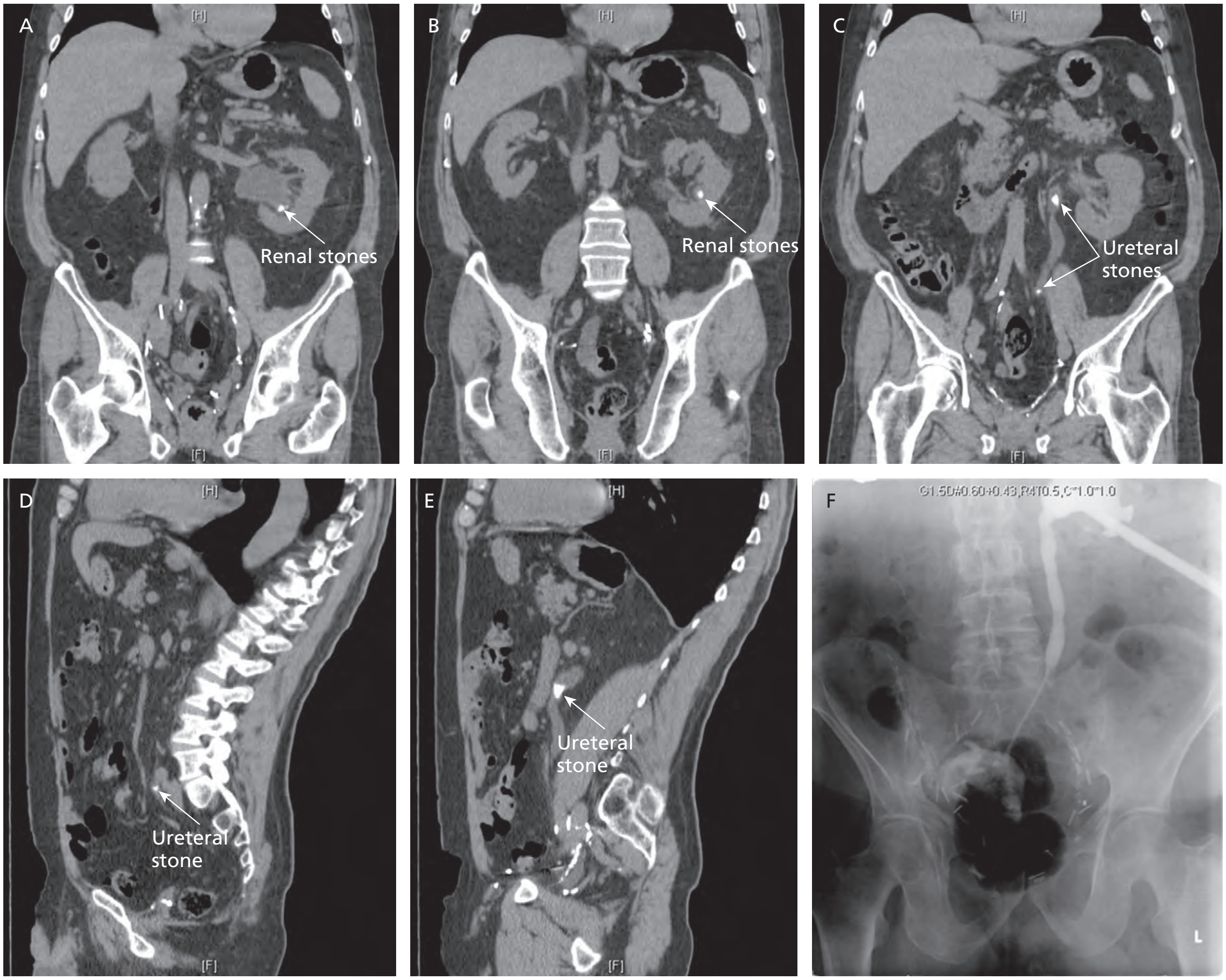


Figure 64.2 (A, B) Renal and (C–E) ureteral stones in a patient with ileal conduit. (F) Postoperative nephrostogram.

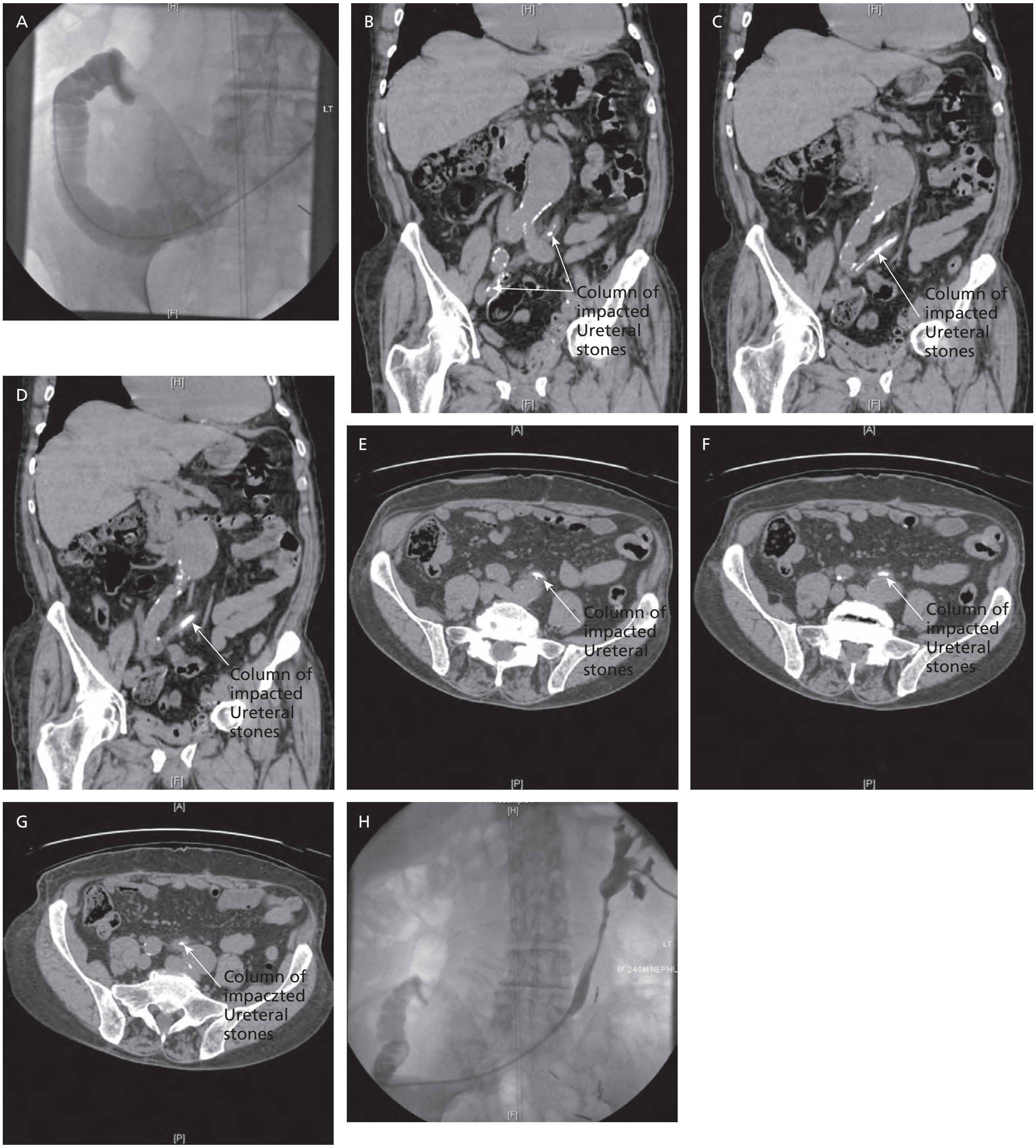
conduit. A loopogram can aid in the diagnosis of stomal stenosis and, if present, will need revision in addition to removal of the stone().

Continent diversions (Figures 64.4–64.7)

Much like loop diversions, low pressure–high volume pouch continent diversions can be constructed using the stomach, ileum, or colon. Most often, the right colon and ileum are used. They can be placed in an orthotopic location and anastomosed to the native urethra, or cutaneous catheterizable stomas can be constructed. The continence mechanisms vary from appendix to tapered ileal segment for cutaneous diversions, and native striated urethral sphincter for orthotopic diversions [17, 18].

For continent diversions, risk factors for stone formation are directly related to residual urine, mucus accumulation due to lack of irrigation, acidic urine, and bacterial colonization [1, 19, 20]. Maintenance of the continence mechanism is of paramount importance as this can be very tenuous. Due to the risk of incontinence and strictures or stenosis, stomal access is discouraged for continent diversions, except as a means to fill the pouch. If the stone burden is minimal, then stomal access for continent diversions or urethral access for orthotopic pouches, can be used with rigid or flexible instrumentation. Fragmentation can be performed with any of the available techniques: holmium laser, pneumatic, mechanical or electrohydraulic lithotripters. For larger stone burdens or when there is concern about damage to the continence mechanism, a percutaneous approach should be used.

For pouch access, it is imperative to review preoperative CT scans to determine the location of adjacent bowel and other vascular structures. Ultrasound guidance may also be a useful aid intraoperatively. One technique is placement of a flexible endoscope through the stoma or urethra and deflecting anteriorly to transilluminate the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[F]

Figure 64.3 (A) Redundant ileal loop in a patient with a (B–G) column of impacted ureteral stones. (H)Postoperative nephrostogram.

proposed site, followed by percutaneous puncture onto the light. In this manner, the entire access and dilation can be performed under direct visualization. Once dilation is completed, Amplatz-type sheaths or laparoscopic trocars can be used. For the laparoscopic approach, separate camera and working ports can be placed as needed. Fluoroscopic guidance is indispensable since stones can be hidden behind folds within the pouch. With the sheath in place, a rigid nephroscope with its sizeable working port can be used with any of the intracorporeal lithotripters. Fragment extraction can become problematic, but this can be easily overcome by placing a

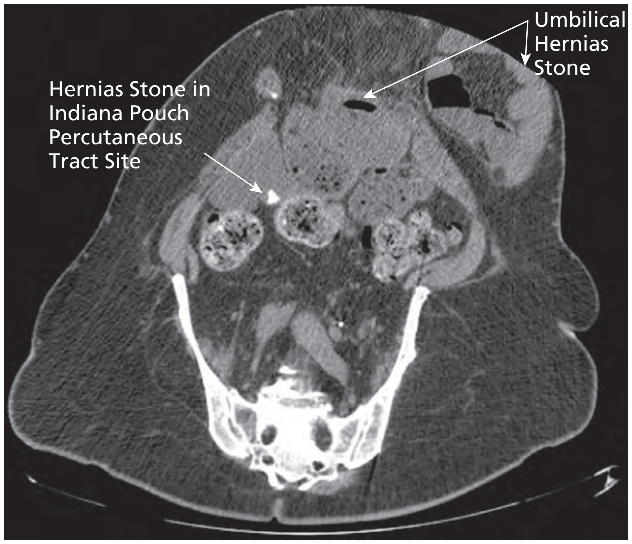
Umbilical Hernias Stone
Hernias Stone in Indiana Pouch Percutaneous Tract Site

Figure 64.4 Stone in an Indiana pouch. Arrow identifies the ideal percutaneous tract.

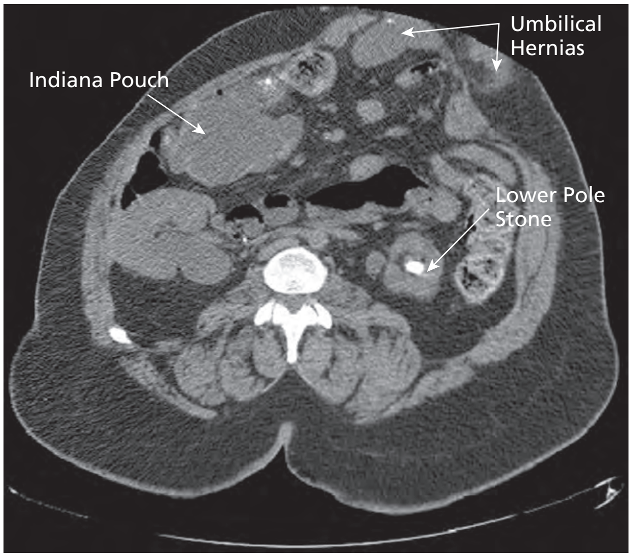
Umbilical Hernias
Indiana Pouch
Lower Pole Stone

Figure 64.5 Lower pole renal stone in a patient with an Indiana pouch.

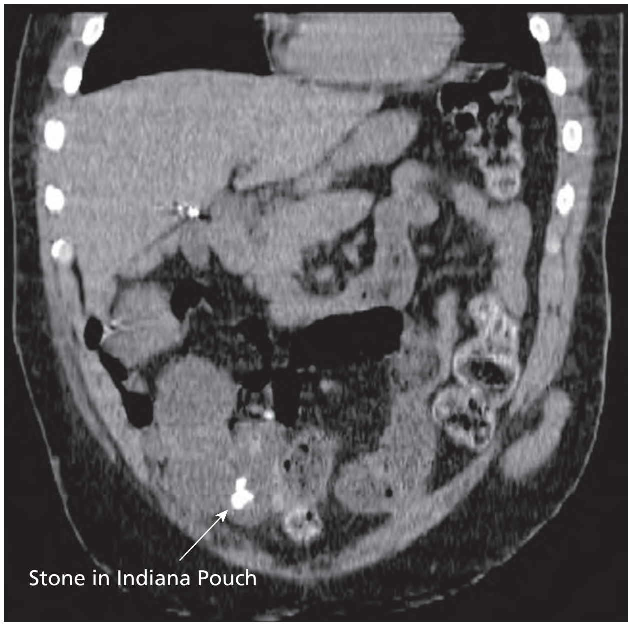
Stone in Indiana Pouch

Figure 64.6 Stone in an Indiana pouch.

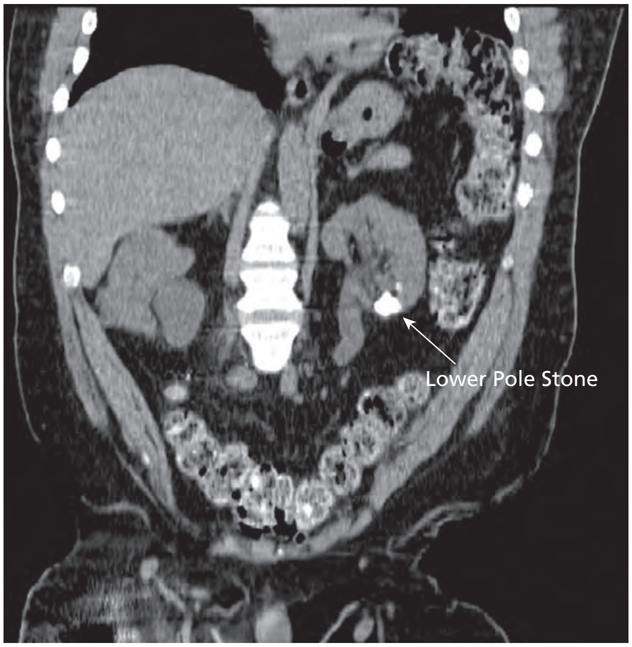
Lower Pole Stone

Figure 64.7 Lower pole renal stone in a patient with an Indiana pouch.

laparoscopic Endo-catch entrapment bag to hold the stones. Lithotripsy can then proceed inside the bag. An alternative approach is to widen the skin incision and extract the bag with the stones intact [21–27]. Laparoscopic ureterolithotomy is also an option; however, this requires advanced laparoscopic skills. Open cystolithotomy is also an option, but is very seldomly used given the availability of minimally invasive percutaneous techniques [28–32] (Figures 64.1, 64.4–64.7).

Cohen *et al.* recommend ultrasonic over electrohydraulic lithotripsy, since the stones can be fragmented and evacuated with suctioning with fewer passes of the instrument across the efferent limb, thereby decreasing risk of injury. Additionally, the ultrasonic waves do not injure the intestinal mucosa, in contrast to the electrohydraulic lithotripter which can cause significant mucosal trauma [12]. Most authors agree that ESWL with or without trans-stomal endoscopic extraction can be effective for small stone burdens. These approaches are limited by small stoma size and the continence mechanism, which restrict the use of larger size instruments capable of treating larger stones.

In the hands of a skilled endourologist, minimally invasive approaches may be used to treat large stones up to 4–5 cm in diameter [21] and even multiple pouch calculi in patients with continent diversions, without disrupting the continence mechanism [12]. Other authors have demonstrated that in the right hands, trans-stomal endoscopic removal of stones results in minimal complications, while anesthetic requirements and length of hospitalization are reduced [33]. However, all continence mechanisms are not alike and therefore, it is cautioned that the trans-stomal approach be reserved for diversions with intussuscepted nipple valves of adequate caliber to easily accommodate larger instruments for more efficient stone removal [34].

Percutaneous techniques can be challenging because small fragments can easily be obscured in the mucosal folds of the bowel. These fragments will then act as a nidus for regrowth of new calculi. Even with copious irrigation, the fragments may remain. A second-look endoscopy of the reservoir is of benefit since this can further increase the stone-free rates [35–37].

Drainage

Once stone extraction is completed, the choice of drainage is important. The options include ureteral stents, pigtail nephrostomy tubes, re-entry nephrostomy tubes, nephroureteral tubes, among others. If a completely indwelling drainage system is desired, ureteral stents are the optimal choice. It is important to choose an extra-long ureteral stent to facilitate its removal via a retrograde approach from the reservoir. Often, a string can be left dangling from the stent and out through the stoma to avoid instrumenting the patient when removing the stent. For renal or ureteral stone removal performed through an antegrade approach, a pigtail nephrostomy tube, a nephroureteral tube, or even a re-entry nephrostomy tube can be used, based on the surgeon's preference. If percutaneous access was gained into the reservoir, a separate drain can be placed through the puncture site into the reservoir and removed once the urine is sufficiently clear of blood clots and debris. In cases where strictures are treated, a period of stenting of at least 4–6 weeks is customary before removal of the stent or nephroureteral tube. It is important to reassess the anastomosis after removal of the stent to assure patency. Some patients may ultimately require open reconstruction to revise the anastomosis if the stricture persists.

Prevention and medical management

Lifelong prophylaxis is critical in this patient population because of the high recurrence rate, which Cohen *et al*. estimated to be as high as 63% over 5 years [38]. Adequate oral fluid intake, as in all patients prone to renal calculi, is essential to prevention [39]. Terai *et al*. in their examination of Indiana pouch calculi found no significant difference in most urinary risk factors between patients with and without stones, except for 24-h urine volume, which was significantly lower in stone formers (mean 2.0 L vs 1.6 L, $P < .05$) [1]. These at-risk patients should ideally have a daily urinary output of at least 2 L to significantly impact the risk of stones recurring [39].

Terai *et al*. reviewed overall stone formation rates in diversions performed in the USA and Japan, and found the the Indiana pouch had significantly higher rates of stone formation in Japan. Considering that the overall predisposition for stone formation is lower in Japan than in the USA (5.4% vs 12% lifetime risk of urolithiasis, respectively [40]), the authors identified that the only difference in protocol was the use of frequent pouch irrigations in the USA. Hensle *et al*. demonstrated a significantly lower rate of stone formation for patients placed on a standard prophylactic irrigation protocol [41]. Dumanski *et al*. has postulated that small crystals and intestinal mucus that are not drained with catheterization alone may act as a template for bacterial biofilms and consequently as a nidus for the growth of infection stones [42].

Other prophylactic measures include a regular voiding and catheterization schedule in order to decrease residual urine volume within the reservoir. Complete evacuation is essential since residual urine is considered a more significant risk factor than bacteriuria for calculus formation [9, 43].

As with any patient with recurrent urinary calculi, predisposing metabolic abnormalities also need to be addressed. As many as a third of these patients have low urinary citrate levels (100 mg/day) and are more prone to stone formation [3]. They may be chronically acidotic, which inhibits the renal production of citrate, resulting in hypocitraturia [44]. Decreased urinary citrate levels may also be secondary to decreased renal production of citrate, increased intestinal reabsorption of citrate by the diversion, or a combination of the two [45]. For these patients, oral citrate supplementation is indicated.

Urinary reservoirs are frequently colonized by bacteria. Urea-splitting organisms are often found and they are responsible for the formation of magnesium ammonium phosphate stones. If a struvite stone is found, antibiotic therapy is indicated. If stones recur, then prophylactic antibiotics should be considered. Also, the importance of increased fluid intake should not be ignored [9]. Prophylaxis for struvite stones can also include acetohydroxamic acid, which is an irreversible urease inhibitor [46]. Dissolution therapy for struvite calculi may be effective in eliminating stone fragments. Hemiacidrin or Suby's G solution dissolves struvite and calcium phosphate stones by acidifying the urine and forming calcium–citrate ion complexes [47]. Aluminum hydroxide is another option. It acts by binding phosphate in the gut, thereby decreasing gastrointestinal absorption of phosphate.

Conclusions

Management of urolithiasis continues to be a significant challenge in patients with urinary diversions. Prevention and prophylaxis remain the most important management strategies. Prophylaxis with increased fluid intake, regular voiding and catheterization schedules, frequent pouch irrigation, antibiotic prophylaxis, and when indicated, other adjuncts such as citrate supplementation or use of urease inhibitors, are all of tremendous importance as management strategies. Additionally, elimination of any nonabsorbable elements during construction of the diversion will serve to lower the incidence of stone formation. Minimally invasive and endourologic techniques have broadened the available choice in the surgical management of these patients, decreasing the morbidity and shortening the convalescence associated with treatment of these stones.

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CHAPTER 65

Management of Pediatric Stone Disease: Endourologic Techniques*

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Introduction

The surgical management of urolithiasis in children is dramatically evolving. Over the past two decades, the advent of shock-wave lithotripsy (SWL) has revolutionized pediatric stone management and SWL is currently the procedure of choice in treating most upper tract calculi in industrialized nations. However, with miniaturization of equipment and refinement of technique, endoscopic access to the entire pediatric urinary tract is now possible, and in westernized countries open stone surgery has become obsolete. In a growing number of centers, ureteroscopy (URS) is being performed in cases that previously would have been treated with SWL or percutaneous nephrolithotomy (PCNL), with demonstrable efficacy and complication rates in retrospective series. This chapter provides a directed review of the literature, focusing on recent advances in the surgical management of pediatric stone disease.

Incidence of urolithiasis in children

The incidence and characteristics of nephrolithiasis in children reflect a wide geographic variation, but stones occur in children of all ages without clear gender predominance [1]. Although uncommon in the western hemisphere, pediatric stone disease is considered endemic in developing nations, including India, Turkey, Pakistan, and the Far East. In these areas, ammonium acid urate and uric acid stones predominate, strongly implicating dietary factors [2]. Despite this discrepancy between hemispheres, nephrolithiasis in children is increasing in occurrence globally [3], likely reflecting westernized lifestyle and dietary changes, including higher salt and carbohydrate intake with processed foods and decreased water consumption [4].

It is established that children with anatomic abnormalities, urinary tract infections, and metabolic disturbances are considered to be at high risk for stone development [5]. In developing nations, recent reports suggest that a metabolic risk factor can be found on urine studies in 84–87% of children, most commonly hypercalciuria or hypocitrauria [6, 7]. However, evidence is accumulating that stones in a majority of westernized children are calcium based without any evidence of metabolic abnormality on 24-h urine collection [8]. In a retrospective study of 1440 Pakistani children, Rivzi *et al*. reported that while diet, dehydration, and poor nutrition remain the major causative factors of pediatric nephrolithiasis, there is an emerging predominance over the past decade of upper tract calculi, which is more consistent with adult populations [2]. Recent data support this trend: in a modern series of 150 children managed over an 8-year period, Kalorin *et al*.

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reported that 57% of stones detected in children younger than 10 years of age were located in the upper tract [9].

Diagnosis

Radiologic evaluation and surveillance

Radiographic assessment of the child with calculus disease must be accurate, economic, and safe**.** The goals include determination of stone location, size, density, and urinary tract anatomy. Indications for assessment include acutely symptomatic children with a suspected calculus, or children with known calculus disease requiring follow-up evaluation to either determine stone burden or recurrence. Radiographic evaluation is also important in children with abnormal urinary tract anatomy that may predispose to calculus formation requiring eventual surgical management. Renal calculi in neonates and younger children are often diagnosed with ultrasound. While anatomic location and the associated presence of hydroureteronephrosis can be accurately assessed in a majority of children, up to 40% of calculi may be missed using ultrasound [10]. Despite the increased sensitivity of computed tomography (CT) compared to ultrasound [11], concerns regarding radiation exposure limits its use in young children. Although speculative, risk as high as one fatal cancer for every 1000 CT scans performed in young children have been reported [12]. Recently, investigators have begun to reassess diagnostic thresholds in an effort to reduce radiation exposure without sacrificing diagnostic efficacy, particularly in children with complex stone histories requiring serial imaging studies [13]. Radiation exposure can also be reduced effectively by reducing the number of CT examinations performed for poor clinical indications, scanning only the anatomic region of interest, and by not performing both unenhanced and contrast-enhanced scanning unless absolutely necessary [14].

In our practice, asymptomatic calculi incidentally diagnosed with ultrasound are followed with serial ultrasound or plain abdominal films to minimize radiation exposure. Noncontrast helical CT is our diagnostic test of choice in older children presenting acutely with flank pain, but is reserved for younger children in whom plain films or ultrasound are nondiagnostic. CT can also be useful in demonstrating secondary signs of acute obstruction, such as hydroureteronephrosis, renal enlargement, and perinephric or periureteric stranding; however, the latter findings may be less obvious or absent in pediatric patients due to their comparatively less retroperitoneal fat [15–17]. Postoperative or surveillance imaging is individualized and based on age, anatomy, stone burden, and any underlying metabolic abnormality with the goals of maintaining diagnostic accuracy as well as minimizing radiation exposure.

Fluoroscopy has an important role in the realtime detection and management of urolithiasis in children, and the same important safety concerns exist with respect to radiation exposure as with CT. C-arm fluoroscopy is utilized during the surgical setting to assist in antegrade and retrograde access of the upper and lower urinary tract, and manipulation of endoscopic instruments *in vivo* often requires realtime fluoroscopic monitoring. Fluoroscopy is also used during SWL to assist in stone localization and to monitor the effectiveness of treatment. Pediatric endourologists must have a working understanding of the principles of fluoroscopy and be aware of the intraprocedure fluoroscopy time and energy settings to limit radiation exposure to both the pediatric patient and operative staff.

Metabolic evaluation

Following definitive therapy, children are ideally followed in a multidisciplinary stone clinic, including urologic, renal, nutrition, and endocrine evaluation if necessary. Routine evaluation includes urine culture, 24-h urine collection, and office-based ultrasound or abdominal films to detect recurrence. While there is abundant reference material in the adult literature, data regarding standard 24-h urine reference values for stone risk factors in children are just beginning to emerge [18]. Regrettably, there are significant differences between the normal ranges of urine chemistries in children and adults [19, 20], and standardizing 24-h urine parameters for nonstone formers is currently the subject of prospective evaluation at our institution.

In the preliminary evaluation of pediatric stone disease it is common to obtain 24-h urine values for creatinine, sodium, calcium, oxalate, uric acid, and citrate. The very cumbersome nature of a 24-h urine collection often limits its accuracy in the pediatric population. In light of this, random urine spot sample ratios have been used. Urine calcium-to-urine creatinine ratios (Uca:Ucr), for example, have been used with sensitivities and specificities up to 90% and 84%, respectively, in the evaluation of hypercalcuria, a known risk factor for urolithiasis [21]. However, a single test limited to one urinary metabolite cannot be solely relied upon to monitor responses to various medical treatments. Furthermore, it is unreasonable to solely rely on urinary calcium excretion values as an indication of overall metabolic disturbances. It has been suggested that measurement of urinary supersaturation products (calcium oxalate, urate) may help to improve the identification of those children at risk for stone formation. DeFoor *et al.* demonstrated that supersaturation levels of calcium oxalate as well as calcium-to-creatinine ratios were significantly higher in pediatric stone formers compared with control subjects [22]. However, this observed difference may reflect differences found in urine volumes. Lande *et al*. recently observed that low urine volumes in children often negate the benefit of pursuing urine supersaturation products in a stone metabolic work-up [23].

Medical management

Stone disease in the pediatric population has contributing genetic, anatomic, metabolic, and dietary causes. There are numerous genetic causes of hypercaliuric nephrolithiasis alone that contribute to pediatric calculi formation [24]. Taking this into account, proper medical management is essential following spontaneous passage or definitive surgical therapy. Although a detailed assessment of the medical management of pediatric stone disease is beyond the scope of this chapter, a focus on prevention through diet and medication monitoring is crucial to long-term management, and often involves consultation with a pediatric nephrologist.

Conservative management

Conservative management of pediatric nephrolithiasis closely mirrors that of adults. Even in very young children, renal calculi of less than 3 mm are likely to spontaneously pass, and stones of 4 mm or larger in the distal ureter are likely to require endourologic treatment [25]. In our practice, if a child's pain is controlled with oral analgesia, clear liquids are tolerated, and there is no evidence of urinary tract infection, parents are offered a closely monitored trial of spontaneous passage for 4–6 weeks prior to definitive therapy. Based on efficacy demonstrated in the adult population [26], tamsulosin may be offered on an individualized basis as adjunctive therapy to facilitate ureteral expulsion, although there is limited current evidence supporting its effectiveness in children [27]. A ureteral stent is placed acutely in children with evidence of an infected genitourinary system, refractory colic, or uncontrolled nausea and vomiting. Under these circumstances definitive therapy is delayed for 7–14 days following stenting to allow for system decompression, ureteral orifice dilation, and resolution of edema before endourologic management is undertaken [4].

Pediatric considerations

Special considerations in the endourologic management of stone disease in children include preservation of renal development and function, prevention of radiation exposure, and minimizing need for retreatment. Despite advances in endourologic equipment and technique, controversy remains regarding the contribution of SWL to future development of diabetes or hypertension, and whether ureteral orifice dilation during URS leads to ureteral stricture formation or development of vesicoureteral reflux (VUR). International consensus is lacking as to the most effective surgical management of pediatric stone disease due to lack of prospective randomized trials comparing treatment modalities and disparity in the access to emerging technologies. Regardless of treatment modality, the presence of residual stone fragments is associated with adverse clinical outcome [28], and every attempt should be made to achieve a stone-free status. Surgeon experience is paramount to facilitate complete stone clearance and minimize retreatment rates [4]. The decision regarding the most efficacious primary treatment modality must be individualized per child based on age, anatomy, location, and composition of stone burden.

Antibiotic use

Use of perioperative antibiotics in the management of pediatric urolithiasis closely mirrors that in adult patients. Per the 2008 American Urological Association best practice statement on antibiotic prophylaxis, 24 h or less of perioperative antibiotics are indicated in all patients undergoing upper tract instrumentation [29]. Appropriate agents include fluoroquinolones, trimethoprim–sulfamethazole, first- and second-generation cephalosporins, and ampicillin in combination with an aminoglycoside. A urine culture is mandatory before all upper tract procedures to determine if the urine is sterile, and culture results are used to guide preoperative antibiotic therapy, particularly for percutaneous procedures, patients with high-grade obstruction, or patients with an indwelling stent [5]. In our practice, children with a negative urine culture undergoing uncomplicated SWL and URS procedures receive perioperative cefazolin, and all children undergoing a percutaneous procedure or who have a preexisting ureteral stent/nephrostomy tube receive a fluoroquinolone or ampicillin/gentamicin. Use of postoperative antibiotics is controversial and is determined on a per child basis and individual surgeon preference. Recent data demonstrating an increased risk of developing resistant bacterial strains with prolonged use of antibiotic prophylactic therapy [30] have led to many pediatric urologists reconsidering the need for and duration of postprocedure prophylaxis.

Shock-wave lithotripsy

The emergence of SWL revolutionized the minimally invasive treatment of urolithiasis during the early 1980s. Initially reported in children in 1986 [31], large series

Table 65.1 Outcomes of shock-wave lithotripsy in children (modified from Smaldone *et al*. [43], with permission from Elsevier).

Study	Lithotripter	Number of children/ renal units	Mean age (years)	Stone location (%)	Mean size (mm)	Retreatment rate (%)	Stone free (%)	Complications (%)
Myers *et al.* [32]	Siemans Lithostar	446	13.7 R 14.1 U	53.4 R 46.6 U	12.3 R 7.3 U	10.7 R 3.5 U	67.9 R 91.1 U	Sepsis 0.2
Muslumanoglu *et al*. [34]	Siemans Lithostar	344	8.7	57.1 R 42.9 U	N/A	53.9	73.3	Overall 9.6 Steinstrausse 7.8 UTI 1.2 Colic 2.9
Rizvi *et al*. [35]	EDAP LT02 Technomed	262	n/a	67.6 R 32.4 U	N/A	29.5	84.2 R 54.1 U	Colic 10.1 Fever 8.5 Steinstrausse 1.1 Hematuria 11.3
Aksoy *et al*. [37]	Dornier MPL 9000	129/134	8.7	84.4 R 15.6 U	15.7	N/A	85%	Overall 14.7 Steinstrausse 5.4 UTI 7.8 Hematoma 0.8
Raza *et al*. [38]	Piezolith 2300; Dornier Compact Delta	122/140	7.7	N/A	17.9	N/A	69	Fever 2.9 Colic 7.2 Steinstrausse 2.4
Demirkesen *et al*. [39]	Siemans Lithostar	126/151	8 (median)	66.9 R 33.1 LP	10 R 6 LP	40	71.5	Overall 7.2 fever 0.8 Steinstrausse 6.4
Nelson *et al*.[44]	Dornier Compact Delta	111	10.5	87.4 R 12.6 U	8	22	58.6	Overall 7 Obstruction 2 UTI 2 Hematoma 2
Landau *et al*. [41]	Dornier HM3	216	6.6	72.7 R 27.3 U	14.9 R 9.5 U	19.7 R 22 U	80 R 78 U	Overall 2.8 Fever 0.5 Obstruction 0.5 UTI 0.5 Pain 0.9

R, renal; U, ureteral; UP, upper pole; S, staghorn; LP, lower pole; UTI, urinary tract infection.

have reported complication, safety, and stone-free rates comparable to adults [32–39] (Table 65.1). When used as a primary treatment option for upper tract calculi, SWL efficacy ranges from 68% to 84% [32, 35, 40] and has become the preferred treatment modality for uncomplicated renal and proximal calculi of 15 mm or smaller. In a contemporary series of 216 children (mean age of 6.6 years) with a mean stone size of 14.9 mm undergoing SWL with the Dornier HM3 lithotripter, Landau *et al*. reported a 3-month stone-free rate of 80%, demonstrating that efficacious stone-free rates can be achieved in appropriate candidates [41]. Complication rates are minimal, and range in severity from hematuria and ecchymosis to obstruction with sepsis [42]. Although well tolerated in children, current stone-free rates with SWL are difficult to interpret from the existing body of data due to discrepancies between studies with regard to type of lithotripter, number of shocks administered, and retreatment rates [43]. Recent data suggest that stone-free rates in children with a history of a urologic condition or urinary tract reconstruction are quite low (12.5%), and these children may be better served with URS or PCNL [44]. Despite encouraging results, SWL has not been approved by the Food and Drug Administration for use in children, although it is a widely accepted treatment modality.

Technique in children

General anesthesia is administered in a majority of preadolescent children to avoid patient and stone motion and the need for repositioning. With modern lithotripters, intravenous sedation has been successfully employed in select older children [45], but bowel preparation is now rarely utilized to avoid postoperative dehydration and electrolyte imbalances. The number of shocks delivered and the kilovoltage used vary per lithotripter, but the current consensus recommends that low power settings (17–22 kV) be used to prevent stone migration during the procedure, with an approximate goal of 3000 shock waves per session (<2000 in very young children) [42]. A recent report assessed and compared the number and intensity of shock waves required for stone fragmentation in 44 children (mean age 5.9 years) and 562 adults (mean age 40.9 years). With an equivalent number of sessions between groups (1.1 in each), the mean number of shock waves (950 vs 1262, $P < .001$) and the kilovoltage required (11.8 kV vs 12.4 kV, $P < .001$) were significantly reduced in the pediatric cohort [46]. Although controversial and dependent on stone burden and anatomy, we do not routinely stent children prior to SWL. Ureteral catheters are occasionally employed to aid in the localization of radiolucent calculi, and relative indications for preoperative stenting include solitary renal units, staghorn calculi, obstruction, or anatomic variants [43].

Stone size, location, composition, and patient age

While early series focused primarily on the feasibility, safety, and efficacy of SWL in children, recent efforts have centered on identifying demographic, anatomic, and stone-related prognostic factors for treatment success. SWL is currently considered the primary treatment for upper tract calculi of 15 mm or smaller in children [42], but evidence supporting this stone size cut-off is lacking [43]. Ather *et al*. analyzed the correlation between stone size and clearance in 105 children younger than 14 years of age. They reported an overall stone-free rate of 95% after a mean of 1.7 treatments, with 5% of patients requiring additional procedures as adjuncts to SWL. With a maximum of 30 mm, mean stone size in the treatment success group was 14 mm compared to 16 mm in the treatment failure group [36]. In contrast, using two second-generation lithotripters in 148 children and adolescents, Elsobsky *et al*. reported stone-free rates of 91% versus 75% for mean stone diameter less than and greater than 10 mm, respectively [33]. Investigating stone-free outcomes with the Dornier DoLi S device in 24 children with large stone burdens (mean stone size 31 mm), Shouman *et al*. reported stone-free and complication rates of 83% and 25%, respectively, utilizing 53 sessions and a mean number of 3489 shock waves per session [47]. While these series demonstrate that it is possible to treat very large stone burdens with SWL, the necessity of greater number of shock treatments, more frequent retreatment sessions, and increased risk of postoperative obstruction are still concerning. Further study delineating a clear size cut-off for uncomplicated upper tract stone burden is required to effectively counsel parents regarding the most effective first-line therapy for renal calculi between 1 and 1.5 cm [43].

Renal anatomy and stone location have been subjects of recent interest. The subject of frequent debate in the adult population, the most effective management of lower pole calculi in children has yet to be determined. Stone-free rates from initial small retrospective SWL series range from 56% to 61% [48, 49] with retreatment rates as high as 40% [49]. SWL failure and retreatment rates were associated with increased mean stone burden [49], increased infundibular length [48], and infundibulopelvic angle greater than 45º [48]. Staghorn calculi are uncommon in children and represent a management challenge. Although monotherapy success rates are low in adults, acceptable stone-free rates in children have been achieved with SWL. In 23 children stratified by age with a mean stone burden of 1.6 cm, Lottmann *et al*. reported an overall stone-free rate of 82.6% with only one case of symptomatic obstruction. A ureteral stent was placed in 22% of children, and these authors reported an 88% stone-free rate in children younger than 2 years of age compared to 71% in children aged 6–11 years [50]. In 42 children with a mean stone burden of 3.2 cm stratified by ureteral stent placement, Al-Busaidy *et al*. reported an overall stone-free rate of 79%. While stent placement did not affect stone-free rates, they found that stent placement significantly reduced the major complication rate [51]. The superior success rates with SWL monotherapy in children compared to adults have been attributed to softer stone composition, smaller relative stone volume, increased ureteral compliance to accommodate stone fragments, and smaller body volume to facilitate shock transmission [43]. SWL safety and efficacy have been demonstrated even in very young children. McLorie *et al*. treated 34 children younger than 3.5 years old (mean age 23 months) and reported an 86% overall stone-free rate (66% after one treatment) without major complications [52]. Treatment of proximal ureteral stones has achieved similar success rates to renal stones in most pediatric series, although ureteral stenting is more commonly employed to aid in stone localization and clearance [32]. Treatment of mid-to-distal ureteral calculi has historically been avoided in children due to difficulties with localization over the sacroiliac joint and concern regarding possible injury to developing reproductive systems [43].

SWL success by stone composition is similar between the adult and pediatric populations [4]. Cystine stones are uniquely challenging due to their durability and high recurrence rates. While SWL monotherapy has demonstrated variable results in adults, there are few reports in the pediatric population. In a small recent series, Slavkovic *et al*. reported a 50% stone-free rate in six children with cystine stone burden ranging from 0.2 to 2.5 cm. Although stone-free rates were low, fragmentation was achieved in 100% of patients and stone dissolution was achieved with medical therapy in the remaining children following SWL [53]. Authors have proposed that cystine stones formed within 2 years of therapy may be more easily fragmented with SWL and that stone number and not diameter may be more predictive of success [42].

Limitations and concerns

In children there is currently no consensus regarding the maximum size of residual stone fragments that are considered clinically significant [5, 42] and as a result there is no clear definition as to what constitutes "stone-free" status. While children have been shown to have a greater capacity to clear fragments then adults [54], the presence of residual fragments has been correlated with adverse clinical outcome [28]. Afshar *et al*. followed 26 renal units with residual fragments of 5 mm or smaller and reported that while 31% were asymptomatic with no fragment growth, 69% had adverse clinical outcomes, including fragment growth or clinical symptoms. Patients with residual fragments had a significant increase in adverse clinical outcome compared to stone-free subjects, and the presence of metabolic disorders was associated with fragment growth [28]. For these reasons, metabolic evaluations are now routinely being performed in children with a history of calculi and every attempt should be made to achieve a stone-free status. It is currently unclear if placement of a ureteral stent prior to SWL facilitates fragment passage and improves stone-free outcomes. Although prestenting rates are not consistent across series, current relative indications include cases of solitary kidneys, staghorn calculi, large ureteral calculi, obstruction, or abnormal anatomy, and are not based on total stone burden [4].

While SWL is well tolerated in children with few complications, stone-free rates following single-session monotherapy remain as low as 44% [34]. As a result children are subjected to multiple treatments requiring general anesthesia [45], which is concerning since the effects of shock waves on renal tissue are unclear. Recent evidence from the adult population indicates that shockwave therapy results in renal vessel vasoconstriction and that renal tubular injury and subcapsular hematoma from cavitation and shear forces are dependent on the kilovoltage applied [55]. In an important study examining the long-term consequences of SWL, Krambeck *et al*. reported an increased risk of hypertension and diabetes mellitus related to bilateral treatment, number of administered shocks, and treatment intensity in 340 adult patients with a mean follow-up of 19 years post SWL [56]. Although these results are concerning, differences between pediatric and adult populations and limitations inherent to a questionnaire-based retrospective study make application of these data in children difficult. Retrospective studies in children have reported encouraging data that SWL and PCNL do not result in renal morphologic or functional alteration measured by glomerular filtration rate (GFR) and serial DMSA functional studies [57], but to date long-term data are unavailable. Long-term prospective data are clearly warranted to eliminate confounding variables and to fully assess the risks of chronic damage from SWL to developing kidneys.

Percutaneous nephrolithotomy

The safety and efficacy of PCNL for large stone burdens in the adult population have been well established [58]. Initial concerns with PCNL in children included the use of large instruments in pediatric kidneys, parenchymal damage and its potential effects on renal function, radiation exposure with fluoroscopy, and the risks of major complications, including sepsis and bleeding [43]. However, with increasing experience [35, 59–65] (Table 65.2), success rates utilizing PCNL as monotherapy or in combination with SWL (sandwich therapy) ranging from 68% to 100% have been reported [35, 66]. Although there is no current international consensus, relative indications for PCNL as primary therapy in children include large upper tract stone burden (>1.5 cm), lower pole calculi greater than 1 cm, concurrent anatomic abnormality impairing urinary drainage and stone clearance, or known cystine or struvite composition [5, 42].

Initially described in children by Mor *et al*. in 1997 [67], early pediatric PCNL series described the use of adult-sized instruments. Although initial series avoided performing PCNL in very small children (<5 years of age) due to concerns regarding parenchymal damage, recent data have suggested that PCNL is possible in very young children using adult-sized equipment and access tracts as large as 30F [60, 62, 64, 68, 69]. Despite these successes, early efforts focused on developing technology to minimize percutaneous tract size without affecting PCNL efficacy. Jackman *et al*. developed a novel percutaneous access technique ("mini-perc") using an 13F peel-away vascular access sheath and reported an 85% stone-free rate for 11 procedures in seven children with a mean age of 3.4 years [70]. The benefits of minimal tract dilation include increased maneuverability, decreased blood loss, and shorter hospital stay. However, theoretical limitations, including prolonged operative times and impaired visualization from bleeding, imply that this technique may not be adequate for very large stone burdens [43]. Recent advances in instrumentation, such as smaller nephroscopes (15–18F), balloon dilation

Table 65.2 Outcomes of percutaneous nephrolithotomy in children (modified from Smaldone *et al*. [43], with permission from Elsevier).

Study	Number of children/ renal units	Mean age (years)	Stone size (mm)	Transfusion (%)	Stone free (%)	Sandwich therapy (%)	Complications (%)
Badawy *et al*. [59]	60	6	N/A	3.3	90	1.7	Fever 8.3 Colon injury 1.7 Urine leak 3.3 Open conversion 5
Zeren *et al*. [60]	55/62	7.9	16.8	23.9	86.9	1.6	Fever 29.8 Open conversion 1.6
Rizvi *et al*. [35]	62	n/a	47	25.3	67.7	27.4	Open conversion 4.8 Fever 46.8 Urine leak 6.4 Hydrothorax 1.6
Desai *et al*. [61]	56	9.1	18.4	14.3	89.8	5.4	Urine leak 5.4
Salah *et al*. [62]	135/138	8.9	22.5	0.7	98.6	0	Urine leak 8
Holman et al. [63]	138	8.9	22.5	0.4	98.5	0	Fever 1.1 Urine leak 8
Samad *et al*. [64]	169/188	8.2	27.2	4	59.3	34.5	Fever 42.8 Hyponatremia 0.1 Obstruction 0.1
Shokeir *et al*. [65]	75/82	6.6	14.4	1.2	95.1	4.8	Urine leak 1.2

EHL, electrohydraulic lithotripsy; US, ultrasound; HL, holmium laser.

catheters, and more efficient energy sources for intracorporeal lithotripsy, have greatly facilitated percutaneous treatment techniques. As a result, open surgery has largely been supplanted by PCNL as the treatment of choice for large stone burdens in children of all ages.

Technique in children

Prior to PCNL, all films must be thoroughly reviewed to determine if the patient's stone burden is amenable to a percutaneous approach. The risks of PCNL must be completely discussed with the consenting parent or guardian. It must be understood that a percutaneous procedure carries risks that are not limited to but include bleeding requiring transfusion, delayed renal hemorrhage requiring angioablation, sepsis, pneumothorax, hemothorax, urothorax, incomplete stone treatment, and injuries to organs adjacent to each respective kidney. A urine culture 2–3 weeks prior to an elective procedure is mandatory in every pediatric patient, and every attempt should be made to treat preoperative urinary tract infections and minimize asymptomatic bacteriuria prior to therapy. In some cases, including children with complex anatomy or pre-existing stent/nephrostomy tube placement, even with a negative preoperative culture, 3–5 days of antibiotic prophylaxis may be warranted. In all cases, broad-spectrum intravenous antibiotics should be administered perioperatively (see above).

All percutaneous procedures are performed using general anesthesia and antibiotic prophylaxis. A warm operating room, body-temperature isotonic irrigant, brief anesthetic induction, short operative times, proper draping, and monitoring of body temperature should decrease the incidence of hypothermia and hyponatremia [43]. After induction of anesthesia with the patient in the lithotomy position, a retrograde pyelogram is performed to outline the collecting system and an occlusive balloon catheter is left *in situ* (Figure 65.1). The patient is then repositioned in the prone position with the torso elevated at 30° from the table surface with a towel roll [42]. Circumstances that require special consideration involve children with spinal anomalies such as spina bifida. In these patients, positioning can be a challenge due to existing spinal hardware and limb contracture [71]. Patients who have had prior spinal surgery consisting of vertebral fusion or Harrington rod placement will have restricted spinal mobility, spinal curvature, and/or atrophic or contracted extremities. Assessing the degree of mobility in the trunk and extremities is crucial in planning for PCNL in these patients. These patients must be placed in the most comfortable position possible without excessive contortion or flexion of the joints (Figure 65.2). In addition, as a result of spinal curvature, renal anatomy is altered and the risk of visceral injury and pneumothorax with percutaneous access is increased. Special attention must be paid to latex precautions in the myelomeningocele population

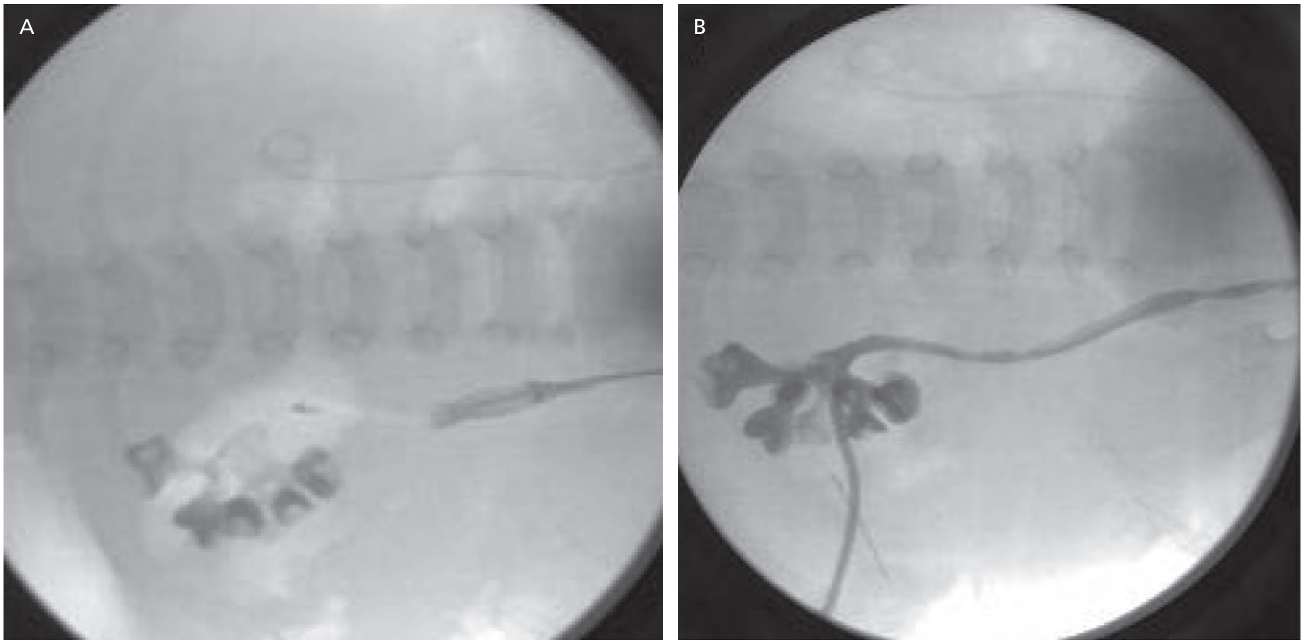

Figure 65.1 (A) Retrograde pyelogram showing a filling defect from a partial staghorn calculus in a 22-month-old male awaiting small bowel transplant for congenital tufting enteropathy. (B) Antegrade nephrostogram following "mini-perc" nephrolithotomy demonstrating clearance of the stone and patency of the ureter.

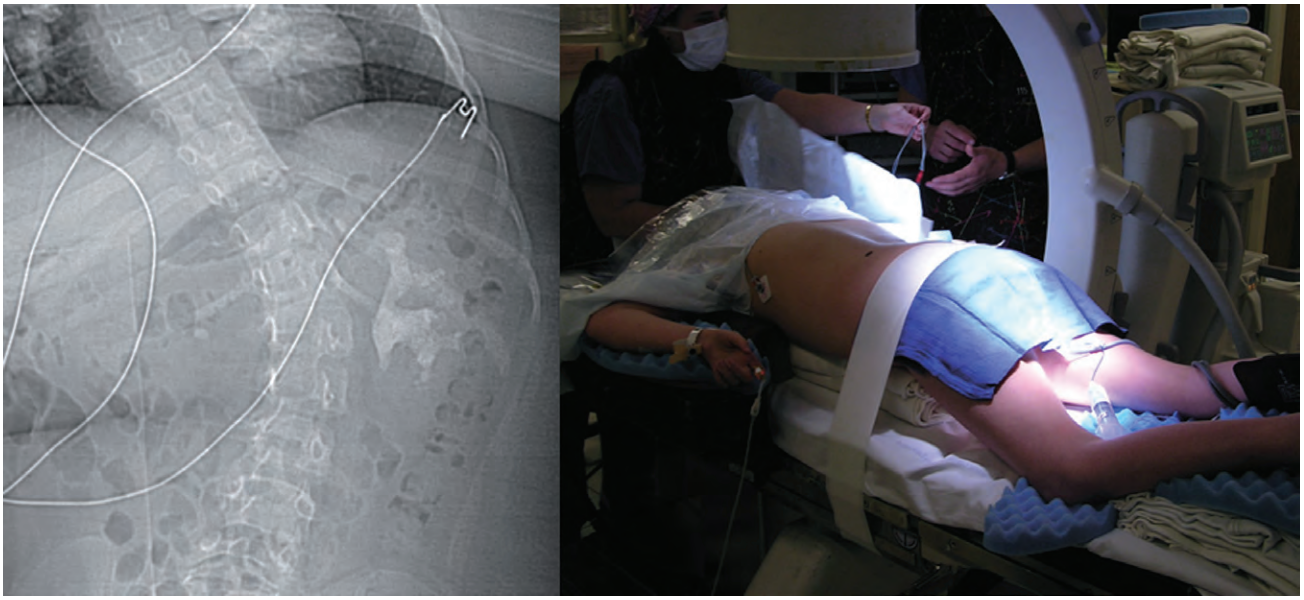

Figure 65.2 Spinal curvature prevents optimal positioning in a 10-year-old female patient with spina bifida undergoing percutaneous nephrolithotomy for a left complete staghorn calculus. As a result of spinal curvature and/or reconstruction, renal anatomy can be altered, increasing the risk of visceral injury and pneumothorax with percutaneous access. In these complex cases, extreme care must be taken to pad all joints in the prone position.

and, as in all cases, proper padding of pressure points is mandatory.

After selection of the desired calyx with the assistance of fluoroscopy in two planes, a 16G or 18G spinal needle is placed in the 30° position. The ideal tract is one that provides the shortest and most direct access to the stone. For complex calculi occupying multiple calyces including the lower pole, a supracostal posterior access is preferred to provide visualization of the superior calyx and pelvis, access to the pelvis and ureter, and straight access

Image not available in the electronic edition

Figure 65.3 (A) "Mini-perc" access technique utilizes a 13F x 11.5-cm peel-away vascular access sheath with an exposed trocar length of 1 cm (Mini-PERC™, Cook Medical Inc, Bloomington, IN, USA).. Insertion of the sheath into the collecting system can be performed with a single pass over an access wire and does not require sequential or balloon tract dilation, facilitating placement of a flexible cystoscope or ureteroscope for stone fragmentation and clearance (reproduced courtesy of Cook Medical Inc). (B) As an alternative to using sequential dilators in larger children, balloon dilation (X-Force™ N30 Nephrostomy Balloon Dilation Catheter; Bard Medical, Covington, GA, USA) of the nephrostomy tract permits dilation and sheath placement in a single step, thereby minimizing potential parenchymal trauma and bleeding (reproduced courtesy of Bard Medical Division).

to the inferior calyces, allowing easier manipulation of the working instruments and minimizing torque on the collecting system [72]. Following initial puncture, no attempt should be made to redirect the needle while it is located within the cortex of the kidney to avoid trauma. After access is confirmed with urine or irrigation return, a flexible guidewire is placed into the collecting system through the needle and directed down the ureter into the bladder. A small skin incision is made with a No. 11 scalpel, and 8F and 10F coaxial dilators are passed over the guidewire into the collecting system. Once in place, an Amplatz Super Stiff™ guidewire (Boston Scientific, Natick, MA, USA) is placed as a working wire.

Tract dilation can be performed by several techniques. Serial dilation with Amplatz dilators over working wires and subsequent sheath placement under fluoroscopic guidance is the most common technique employed. Alternatively, a 13F peel-away sheath (Docimo Mini-Perc, Cook Urological Inc, Spencer, Indiana, USA) and trocar are passed over the wire into the calyx under fluoroscopic guidance and the trocar is removed (Figure 65.3A). We have also had success using balloon dilators for nephrostomy tract dilation (Figure 65.3B). This technique permits dilation and sheath placement in a single step, thereby minimizing potential parenchymal trauma and bleeding from sequential dilation with metal dilators. While the decision to proceed with mini-perc or dilation is individualized based on child's age, anatomy, and stone burden, familiarity with all of the above techniques facilitates complete access with minimal morbidity.

Once access is obtained, nephroscopy and nephrolithotomy can be performed with a variety of energy sources for stone fragmentation. The outer diameter of nephroscopes range from 17F to 26F and a 15F flexible nephroscope with a 6F working channel has also been developed (Figure 65.4). In addition, 7F and 8F offset cystoscopes with 5F working ports and 7–9F flexible ureteroscopes can be used through an 11F access sheath with enough clearance to allow low pressure irrigation [5]. Energy sources currently utilized include ultrasonic lithotripsy, electrohydraulic lithotripsy (EHL), and the holmium laser, although individual preference is determined by availability and surgeon experience. Postoperative stenting and/or placement of a nephrostomy tube are both patient and surgeon dependent and vary between series. Similar to adult procedures, tubeless PCNL has theoretical advantages, including decreased postoperative pain and a short hospital stay, but currently data are limited in the pediatric population [73].

Outcomes

Recent large retrospective series of PCNL monotherapy have demonstrated high efficacy rates approaching 90% [60, 61, 68]. In 56 children with a mean age of 9.1 years and a mean stone burden of 337.5 mm^2, Desai *et al*. reported a stone-free rate of 89.8% utilizing EHL through a 14F nephroscope and a 20–24F sheath. Of these, 61% required multiple tracts and 45% were staged procedures. They reported that the number and size of tracts were significantly associated with postoperative hemoglobin decrease and overall transfusion rate (14%) [61]. In 52 children with a mean age of 7.9 years and a mean stone burden of 282 mm^2, Zeren *et al*. reported an 87% stone-free rate using ultrasound and EHL for fragmentation and tract dilation from 18F to 30F. While prevalent

Image not available in the electronic edition

Figure 65.4 The 20.8F Percutaneous Universal Nephroscope has a large (14F) oval working channel that accommodates instruments up to 3.5 mm in diameter, including the standard ultrasonic lithotripters, while allowing for effective irrigation (top). The 15/18F Miniature Nephroscope is ideal for "mini-perc" procedures, as it can be used with access sheaths as small as 13F. It has an offset eyepiece and a 6F working channel (bottom) (reproduced courtesy of Richard Wolf).

complications included postoperative fever (30%) and need for transfusion (24%), transfusion was significantly associated with operative time, sheath size, and stone burden [60]. In 135 children aged 8.9 years with a mean stone burden of 507 mm^2, Salah *et al*. reported a 98.5% stone-free rate utilizing ultrasound through a 26F nephroscope. Complication rates were low (8% urine leak, 0.7% transfusion), with only one patient requiring a second procedure [62]. In a recent series of 46 children with a mean stone burden of 332 mm^2, Bilen *et al*. reported an 88% stone-free rate using EHL, ultrasound, and the holmium laser. When stratified by tract size (14, 20, and 24F), efficacy rates were similar in all groups, but there were no complications or transfusions in the 14F tract group [68]. Similar to the adult population, these large series utilizing primarily adult-sized instruments demonstrate that both stone clearance efficacy and transfusion rates are related to the size and number of access tracts utilized [74].

In an effort to reduce the number of tracts and associated morbidity, some centers advocate the use of primary PCNL with adjunctive SWL therapy to clear residual stone fragments, although this has largely fallen out of favor in the adult population [75]. In a small series of 29 children with a mean age of 3.8 years and a mean stone burden of 2.4 cm, Mahmud *et al*. reported a 60% stone-free rate after PCNL monotherapy using EHL through a 17F angled nephroscope. A single tract was utilized in all patients, and after SWL sandwich therapy the stone-free rate increased to 100% [66]. In a larger series of 169 children with a mean stone burden of 3.1 cm, Samad *et al*. reported a 59% monotherapy stone-free rate with 96% of cases performed through a single tract. Approximately one-third of primary failures were treated with SWL; the cumulative stone-free rate in all patients was 93.8% with a 3.6% transfusion rate [64]. When stratified by age, anatomy, bilaterality, and renal function, stone-free outcomes were equivalent in all groups. The decision to follow PCNL with SWL is related to operator experience with percutaneous technique and available technology, and is largely utilized outside of the USA. At our institution, our preference is to perform a second-look nephroscopy through the original tract to ensure stone-free status during the initial hospital admission rather than progress to SWL sandwich therapy. Endoscopic surveillance during the initial procedure can determine the need for second-look nephroscopy without relying on additional imaging and the associated risks of radiation exposure [76]. Following our adult endourologic counterparts, we anticipate that further developments in technique will include adoption of tubeless techniques, supine positioning, and modifications to facilitate smaller nephroscopy access tracts. New-generation smaller rigid nephroscopes with improved optics should optimize visualization for stone clearance with the potential to minimize tract size and postoperative morbidity [4]. Technically challenging in nature, surgeon experience with PCNL is paramount in developing individualized treatment plans to optimize efficacy with minimal morbidity [43].

Table 65.3 Outcomes of rigid and flexible ureteroscopy in children (modified from Smaldone *et al*. [43], with permission from Elsevier).

Study	Number of. children/ procedures	Mean age (years)	Stone size (mm)	Stone location (%)	Ureteral orifice dilation (%)	Stone free (%)	Staged (%)	Postoperative stenting (%)	Complications (%)
Rigid ureteroscopy for mid-to-distal ureteral calculi									
Al-Busaidy *et al*. [82]	43/47	6.2	12.6	100 U	N/A	93	N/A	N/A	Ureteral perforation 4 Ureteral stricture 2 Fever/VUR 12
Bassiri *et al*. [83]	66/66	9	8	100 U	37.9	88	N/A	N/A	Renal colic 1.5 Gross hematuria 16.7 Pyelonephritis 4.5
Raza *et al*. [84]	35/52	5.9	9.4	100 U	3.9	79.3	28.6	N/A	Ureteral stricture 2 Fever 10 Ureteral perforation 6
Rigid and flexible ureteroscopy for upper tract and renal calculi									
Minevich *et al*. [81]	58/65	7.5	N/A	64.6 U 35.4 P	30	98	N/A	85	Ureteral stricture 1.3
Smaldone *et al*. [86]	100/115	13.2	8.3	52 R 48 U	70	91	9	75	Ureteral perforation 4.2 Ureteral stricture 1
Cannon *et al*. [88]	21/21	15.1	12.2	100 LP	81	76	14	71	0
Corcoran *et al*. [87]	47/61	9.4	10.2	100 R	91	88	26	70	Ureteral perforation 9
Kim *et al*. [90]	167/170	5.2	6.1	60 P 40 U	0	77.3	N/A	98.2	0
Tanaka *et al*. [91]	50/52	7.9	8.0	75 R 25 LP	35	76	34.6	98	Nausea/pain 2

EHL, electrohydraulic lithotripsy; HL, holmium laser; R, renal; U, ureteral; P, proximal; LP, lower pole.

Ureteroscopy

Adoption of URS for the treatment of pediatric stone disease has lagged behind that of adults due to concerns regarding use of large ureteroscopes in small-caliber ureters, a higher post-SWL stone fragment clearance rate compared to adults [54], and the low incidence of stone formation in children. Since the mid 1980s, with the acceptance of SWL as primary therapy for upper tract calculi of less than 1.5 cm, URS has been historically utilized for calculi below the iliac crests, and for upper tract calculi after SWL failure [5]. URS was not considered primary therapy for upper tract stones in children due to concern for ureteral ischemia, perforation, stricture formation, and development of VUR as a result of dilation of small-caliber ureteral orifices [43].

With significant improvements in both the miniaturization and durability of endoscopic equipment and the widespread acceptance of the holmium laser, URS has become a more attractive option in young children [4]. First described by Ritchey *et al*. in 1988 [77], early series utilizing rigid URS for distal ureteral stones reported stone-free rates ranging from 86% to 100% with low complication rates [25, 35, 78–81]. In a comparison of 31 children randomized to URS or SWL as primary therapy for distal ureteral stones, De Dominicis *et al.* reported a significantly higher stone-free rate after one treatment (94% vs 43%) for children treated with URS [79]. Results from these retrospective studies provide evidence refuting the notion that dilation of the pediatric ureter will result in VUR or the development of ureteral strictures. Supporting this notion, a systematic review of the literature evaluating 221 early pediatric ureteroscopies, Schuster *et al*. noted only two ureteral strictures and a minimal incidence of VUR [78].

Early successes with treatment of distal calculi in children [82–84] have led to a number of centers expanding its utility to the treatment of upper tract calculi (Table 65.3). Results for our institution's and other tertiary care centers' early experiences have demonstrated stone-free rates between 88% and 100%, with complication rates similar to those of the adult population [81, 85–91]. Lesani *et al*. reported their experience using 4.5F, 6F, and 8F rigid URS in treating proximal ureteral stones in 24 children with a mean age of 10.7 years. They did not perform ureteral dilation in any cases, and 100% of children were rendered stone free [85]. In a large series of 100 children with a mean stone diameter of 8.3 mm, 52% of which had upper tract calculi, Smaldone *et al*. reported a 91% stone-free rate, with 9% of children undergoing staged procedures. With a mean follow-up of 10 months, they reported a 4.2% perforation rate managed with ureteral stenting and one distal ureteral stricture requiring open neocystostomy [86]. Corcoran *et al*. reviewed their cohort of 47 children (mean age 9.4 years) with upper tract calculi managed with flexible URS and holmium laser lithotripsy. With a mean stone burden of 10.2 mm, they reported an 88% stone-free rate, with 26% requiring staged procedures [87]. In the largest series to date, Kim *et al*. reported their results in 167 children undergoing 170 flexible URS treatments. Choosing to prestent to allow passive dilation in 95 children (57%) in whom retrograde access could not be obtained, they reported 100% stone clearance for stone burdens of 10 mm or less and 97% for stone burdens greater than 10 mm (mean stone burden 6.1 mm) [90].

As the indications for URS in children continue to expand, acceptable stone-free rates have been reported for increasingly large stone burdens. In 23 children with a mean stone size of 17 mm, Dave *et al*. reported stone-free rates of 75% for renal pelvis calculi and 100% for polar stones. However, in seven children with partial staghorn stones, the stone-free rate was only 14%, implying that complex stone burdens involving more than one calyx may be more amenable to PCNL [89]. Supporting this notion, a recent report observed that 71% of upper tract calculi greater than 10 mm in diameter required more than one procedure to achieve stone-free status [91], indicating that there still is room for improvement in the URS management of the upper tract. Adoption of techniques utilized in the adult population, most notably sequential coaxial and balloon dilation of the ureteral orifice and use of ureteral access sheaths, may facilitate the treatment of larger stone burdens during a single session [43]. Initially described in eight children by Singh *et al.* [92], ureteral access sheaths have been shown to facilitate repetitive upper tract access, reduce intrarenal pressures, decrease operative time, and improve stone-free rates in adults [93]. In our experience, use of ureteral access sheaths and the 6.9F flexible ureteroscope has made possible treatment of lower pole calculi that would have previously required SWL or PCNL. Cannon *et al*. reported a 76% stone-free rate in 21 children with lower pole calculi and a mean stone diameter of 12.2 cm. After a mean of 11.4 months, no major complications were observed [88]. With the transition from SWL to URS as a primary treatment modality at our institution, current relative contraindications to URS management include staghorn stones in recurrent stone formers more amenable to PCNL, anatomic anomalies making retrograde access difficult, and previous endoscopic failure [86].

Technique in children

All URS procedures are performed under general anesthesia to prevent patient movement and minimize the risk of ureteral perforation. Demonstrating sterile urine is mandatory in all patients preoperatively, particularly in patients with indwelling ureteral stents. Following antibiotic prophylaxis, patients are placed in the lithotomy position and rigid cystoscopy (7.5F, 11F, or 18F) is performed to place a safety or working wire. Under fluoroscopic guidance, the guidewire is advanced into the renal pelvis or beyond the level of the stone. Ureteral orifice dilation is performed with 8/10F coaxial dilators (Boston Scientific) in ureters that have not been prestented, or when the rigid/flexible ureteroscope cannot easily be advanced. We generally do not use balloon dilation of the ureteral orifice due to concern for the development of ureteral stricture from ischemia. Our bias is that use of the 8/10F dilator allows for tactile feedback regarding the tightness of the ureter, which is not available with balloon dilation. If we encounter difficulty with the 8/10F dilator, our preference is to place a stent and return for a second procedure rather than to dilate more aggressively [43].

The decision to use a flexible or semi-rigid (6.5–7.5F) ureteroscope depends on size and location of stone, anatomic factors, and individual surgeon preference. A 4.5F rigid ureteroscope is also currently available for use, although our experience with this device is limited (Figure 65.5A). As a general rule, the working port of most ureteroscopes ranges from 2.4F to 3.5F in semi-rigid models and 1.8–3.5F for flexible models. Tip deflection of up to 270° can facilitate access to lower pole calculi, but as in adult patients, difficulty exchanging instruments through the working element of a maximally deflected flexible ureteroscope can limit its effectiveness in some settings (Figure 65.5). Rigid or semi-rigid URS is routinely performed with a safety wire in place, while flexible URS is performed with both safety and working wires in place. Ureteral access sheaths (internal diameter of 9.5F or 12F) are utilized to facilitate flexible URS in cases of large proximal ureteral

Image not available in the electronic edition

Figure 65.5 (A) Pediatric semi-rigid self-dilating ureteroscopes (4.5F/6.5F "Needle" Ureteroscope; Richard Wolf Medical Instruments Corp, Vernon Hills, IL, USA) may be used for rigid ureteroscopy even in toddlers. A 4.5F distal beak allows easier passage to facilitate dilation with the 6.5F proximal component (reproduced courtesy of Richard Wolf Medical Instruments Corp). (B) Technical modifications in newer generation flexible ureteroscopes (AUR™-735 Flexible Pediatric Ureteroscope; Gyrus ACMI LP, Maple Grove, MN, USA) permit direct visualization and access to the entire pediatric collecting system. Small diameter graduated design (7.2F at tip), dual deflection capabilities (160° down deflection, 120° up deflection), advanced fiberoptics, and larger working channels (3.6F) facilitate upper tract access even in tortuous ureters (reproduced courtesy of Gyrus ACMI).

or renal pelvis stone burdens (Figure 65.6). Irrigant, which may be used under pressure, should be isotonic and at body temperature to avoid hypothermia and hyponatremia. Calculi are extracted with a basket when feasible or fragmented using the holmium:YAG laser to facilitate removal. Other energy sources for fragmentation include ultrasound lithotripsy and EHL. The decision to place a ureteral stent postoperatively is based on the duration of the procedure, number of passes with the ureteroscope, and degree of visible ureteral trauma or edema at the conclusion of the procedure [43]. If the patient can tolerate leaving a urethral string in place for 3 days to 1 week, the patient's parents are asked to remove the stent at home; otherwise the stent is removed under brief anesthetic after 7 days.

Concerns and limitations

With smaller, more durable ureteroscopes and improved optics for visualization, URS is becoming more prominent in the pediatric endourologists armamentarium of stone management techniques. However, many unanswered questions still need to be addressed. Concerns for unrecognized ureteral trauma include mucosal flaps and tears, creation of a false passage, perforation, and partial-to-complete avulsion. An injury can occur while dilating the ureteral orifice, introducing the ureteroscope, or during antegrade/retrograde passage of guidewires or baskets, and it is imperative that these injuries be recognized promptly to minimize long-term sequelae. Should a traumatic injury be recognized, immediate discontinuation of the procedure with passage of a ureteral stent is paramount to reduce further ischemic damage and extravasation of irrigant/urine.

In postpubertal children with an adult body mass, URS access is technically similar to the adult population. In the small prepubertal child, questions remain regarding whether to attempt primary treatment without ureteral orifice dilation, perform dilation at the time of definitive therapy, or place a stent and allow the ureter to passively dilate prior to definitive therapy. In 29 children with a mean age of 11 years, Herndon *et al*. performed semi-rigid URS with 4.5F and 6.5F ureteroscopes for distal ureteral calculi. Fourteen percent of the children were prestented, but no child was actively dilated. The ureter was accessed in 100% of cases and the stone-free rate was 96% [94]. Since our flexible and semi-rigid ureteroscopes are 6.9F and 7.5F, respectively, it is our preference to sequentially dilate with the 8/10F coaxial dilator even in very young children, but if we encounter difficulty, a stent is placed rather than dilating more aggressively [43]. While we feel this approach minimizes long-term complication rates, particularly in the management of upper tract calculi, it increases the

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Figure 65.6 (A) Placement of a ureteral access sheath (Flexor®, Cook Medical Inc, Bloomington, IN, USA) provides a continuous working channel (internal diameter ranging from 9.5F to 14F, length ranging from 13 to 55 cm) for the repeated atraumatic introduction of endoscopes and instruments when treating large upper tract stone burdens (reproduced courtesy of Cook Medical Inc). (B) A 1-cm left lower pole calculi in a 16-year-old patient. Following ureteral orifice dilation, a ureteral access sheath (14F internal diameter, 16F external diameter, 35 cm length) is advanced over a guidewire past the pelvic brim. (C) Gaining access to the proximal ureteral (white arrow) facilitated repeat access to the lower pole for stone fragmentation and clearance (black arrow).

number of children who require a second anesthetic and procedure to achieve stone-free status. Our recent finding that 40% of pediatric patients will require at least two procedures to treat upper tract calculi ureteroscopically suggests that with current equipment, the likelihood of achieving a stone-free state after one URS procedure may not be significantly better than with SWL [87]. Another area of contention is the necessity of placing a post-URS stent in all children. While the tendency in large series has been to leave a stent in place after URS manipulation in a majority of children [86], some authors have reported no acute or long-term sequelae despite leaving a post-URS stent in less than 20% of cases [87]. In our practice, a decision to leave a stent is made on an individual patient basis and is based on surgeon preference as well as the degree of visible ureteral trauma at the conclusion of the procedure.

Laparoscopic and robot-assisted pyelolithotomy

Treatment of large stone burdens in children is technically challenging, often requiring multiple procedures. Laparoscopy and robot-assisted laparoscopy has been utilized successfully in adults for the treatment of calculi during the concomitant treatment of ureteropelvic junction obstruction (UPJO) and in the primary treatment of staghorn calculi. Small series utilizing these techniques in children have only recently been described. In eight children (mean age 4 years) with a mean stone burden of 2.9 cm undergoing transperitoneal laparoscopic pyelolithotomy, Casale *et al*. reported a 100% success rate, a mean hospital stay of 2.15 days, and a mean operative time of 1.6 h, with no major complications [95]. In the first report of robot-assisted laparoscopic pyelolithotomy, Lee *et al*. described their experience in five patients; four with cystine staghorn calculi refractory to PCNL and SWL and one with calcium oxalate calculi and concurrent UPJO. Of these cases, four were completed robotically, with one patient having a residual 6-mm lower pole stone and one requiring conversion to an open procedure. Mean operative time in this series was 315 min, mean estimated blood loss was less than 20 mL, and mean hospital length of stay was 3.8 days [96]. These early experiences demonstrate that laparoscopic pyelolithotomy is feasible, safe, and efficacious as an alternative to open pyelolithotomy in children, and warrants further study. However, due to their demanding technical nature, these procedures will likely be limited to endourologic management failures in academic centers with abundant expertise in laparoscopic and robotic pediatric surgery [43].

Management of bladder calculi

Bladder stones are more often found in children from developing countries, are composed of ammonium urate, and are thought to be related endemically to malnutrition [5, 97]**.** In contrast, among children from industrialized nations, bladder stones are most often found in those with spinal cord injuries and/or congenital abnormalities such as spina bifida. Very often these children have undergone augmentation cystoplasty and/or manage their bladders by clean intermittent catheterization. It has been reported that up to 50% of those children with reconstructed bladders will develop a bladder stone(s) in their lifetime, the majority of which are of struvite composition [98]. Authors have postulated that urinary stasis, bacterial colonization or infection with urea-splitting organisms, retained mucous, and foreign bodies are all contributing factors to the formation of bladder stones in these complex children [5].

Historically, open cystolithotomy has been the treatment of choice in the management of bladder calculi. Transurethral cystolithotripsy is an alternative, but it is not ideal in many children due to their smaller caliber urethra or previous bladder neck reconstruction. Percutaneous cystolithotripsy, however, is now utilized worldwide with advantages including shorted hospital stay, improved cosmesis, and a reduction in indwelling catheter duration postoperatively [99]. Currently, percutaneous cystolithotripsy has evolved into the preferred method to treat bladder stones that have formed in naïve and reconstructed bladders alike [100]. In 155 children (mean age 4.5 years) with a mean bladder stone burden of 2.3 cm, Salah *et al*. reported excellent success rates with minimal morbidity utilizing a 26F nephroscope and 30F access sheath introduced through a 1-cm suprapubic incision [101]. A successful modification of this technique utilizing a 16F peel-away sheath and a ureteroscope has been reported even in very young children without negative sequelae [102].

Percutaneous cystolithotripsy in children may be performed under ultrasound or fluoroscopic guidance and is often completed as an outpatient procedure. Depending on imaging preference to aid obtaining access, the bladder is first filled to capacity with water or contrast. The child is placed in the Trendelenberg position to minimize the risk of bowel injury during percutaneous access and tract dilation. An 18G needle

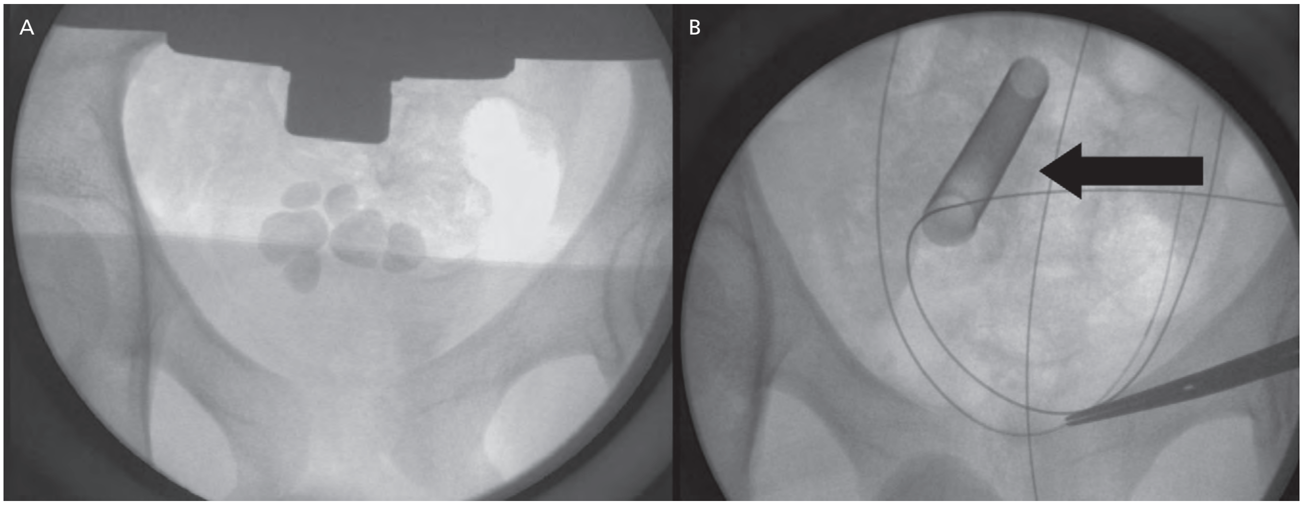

Figure 65.7 (A) A 12-year-old male with a history notable for spina bifida and ileocystoplasty was found to have multiple large bladder calculi on a work-up for recurrent *Proteus mirabilis* infections. (B) Successful percutaneous cystolithotripsy with an ultrasonic lithotripter was performed through a 30F access sheath (arrow).

is placed into the distended bladder in the midline, one to two finger breadths above the pubic bone. Once proper placement is confirmed with return of fluid, a guidewire is passed under fluoroscopic guidance. Similar to percutaneous renal procedures, the size of the access tract is based on the relative stone burden and size of the child (Figure 65.7). In our practice, a 26F nephroscope is used to extract stones of less than 1 cm with a rigid stone forceps or an ultrasonic lithotripter may be used to fragment stones of greater than 1 cm. For very large stone burdens, calculi can be placed in an EndoCatch™ bag (Covidien, Norwalk, CT, USA) prior to fragmentation to facilitate lithotripsy and fragment removal. At the procedure's conclusion, a Foley catheter is left per urethra or a continent catheterizable stoma for 1 week, and the rectus fascia defect is closed with a 2-0 vicryl stitch. Complications are uncommon but include persistent urine leak, bowel injury with access, and damage to the ureteral orifices. Post-operative antibiotic use is variable and depends on preoperative urine cultures, degree of bladder inflammation, or presence of grossly infected urine, and previous urinary tract reconstruction.

Determination of stone-free status

As the surgical management of pediatric stone disease evolves, the lack of a consistent definition of "stone free" following definitive therapy is an issue that remains unaddressed. Although controversial, in select adult patients all stone fragments can be considered clinically significant and can lead to stone recurrence [103]. Likewise, the presence of residual stone fragments in children has been associated with poor outcomes [28], and any size stone fragment in a young stone former may result in the need for repeat surgical procedures. However, these fragments often are not detected on ultrasound or kidney, ureter, bladder (KUB) images, necessitating reliance on CT imaging in select children.

Balancing the risks of radiation exposure for post-treatment stone detection and the risks of anesthesia for secondary procedures is a challenging dilemma for contemporary pediatric endourologists. Newer, high-speed helical CT scanners reduce radiation exposure and rarely require intravenous sedation. In addition, maximizing intraoperative fragment detection by direct visualization in URS and PCNL, and continued development of high -resolution realtime fluoroscopy may result in less reliance on postoperative imaging and decrease the need for second-look nephroscopy/URS, SWL, or sandwich therapy [104]. Until the risks of radiation exposure in children are more clearly defined, surveillance in these children will be individualized based on age, anatomy, stone burden, and underlying metabolic abnormalities [43].

Endourologic management of ureteropelvic junction obstruction

Whitaker test

Diagnosis of the asymptomatic dilated upper tract remains a clinical management challenge. Introduced in 1973, the Whitaker test was developed as a means of diagnosing renal obstruction by directly measuring renal pelvis pressures. The Whitaker test is performed by gaining percutaneous access to the upper tract and placing a Foley catheter to decompress the bladder. With the patient in a prone or semi-prone position, contrast is infused into the renal pelvis at a rate of 10 mL/min. The relative renal pelvis pressure is then calculated by subtracting the measured renal pelvis pressure from the bladder pressure [105]. Relative renal pelvis pressures greater than 22 cmH_2O are defined as obstructed, 15–22 cmH_2O as equivocal, and less than 15 cmH_2O as unobstructed. However, the role of the Whitaker test in the evaluation of hydronephrosis remains controversial. Arguments against point to its invasive nature, large range of equivocal results, super physiologic flow rates (<10 mL/min), and the impact of renal pelvis compliance on test results [106]. Supporters point to its ability to provide realtime information on the collecting system, and to evaluate collecting systems with decreased renal function and those with equivocal findings on renal scintiography [107].

Renal tissue tracer transit time, pressure flow measurements, and Doppler sonography have all been developed as a means of identifying and quantifying upper tract obstruction, but a gold standard has yet to be found. Wahlin *et al*. recently reported their observations in 46 children aged 5–6 months to 12 years of age with hydronephrosis who underwent upper tract pressure flow studies and a Whitaker test prior to pyeloplasty. After identifying 37 patients with obstructed systems, they reported that the pressure flow studies were superior to the Whitaker test by quantifying a value for the degree of obstruction. While the Whitaker test did not provide quantification of obstruction, it confirmed obstruction in 95% of patients, demonstrating its validity as a diagnostic tool in select pediatric patients [106].

Lupton *et al*. recently published a series of 145 adult patients who underwent Whitaker testing over a 25-year period. When compared with diuretic renography, the Whitaker test recharacterized 41% of studies originally interpreted as obstructed systems to be unobstructed, and was able to classify 70% of radiographically "equivocal" systems as obstructed or unobstructed. Based on their results, they advocate the use of a Whitaker test as an adjuvant investigation when there is evidence of obstruction with poor renal function, equivocal results from noninvasive studies with a high clinical suspicion for obstruction, and evaluation of flank pain with an unobstructed renogram [108]. While, there are limited data to support routine use in the pediatric population, it will likely continue to be a useful adjunct study in the small subset of patients whose upper tract obstruction is unable to be fully evaluated by noninvasive means.

Endopyelotomy

Despite its widespread use in the adult population, it was not until the late 1990s that endopyelotomy was evaluated in the pediatric population. Principally based on the intubated ureterotomy, the stenotic or strictured UPJ is incised longitudinally with a holmium laser or cautery/balloon dilation in a full thickness manner via an antegrade or retrograde endoscopic approach, and allowed to heal over a ureteral stent [109]. Initial reports demonstrated encouraging success rates; however, these results were from small cohorts with limited follow-up. In addition, children undergoing antegrade endopyelotomy often required a nephrostomy tube and/or nephroureteral stent and their care was associated with a greater overall cost [110]. In 2004, Tallai *et al*. reported outcomes in 37 children (mean age 11.5 years) undergoing antegrade endopyelotomy over a 12-year period. Despite an overall success rate of 89%, two children required exploration, ligation of the bleeding crossing vessel, and open dismembered pyeloplasty due to postoperative hemorrhage. There were also two children representing with postoperative pyonephrosis who ultimately required nephrectomies[111].

With documented superior success rates of open pyeloplasty even in very young children [112], the indications for endopyelotomy in pediatric patients remain controversial [113]. In addition, with emerging data to support the safety and efficacy of laparoscopic pyeloplasty in children as young as 6 months of age [114], there is minimal evidence to support endopyelotomy as a primary intervention for management of pediatric UPJO. In the adult population, endopyelotomy has been advocated as a salvage therapeutic option after failed pyeloplasty [115]. Initial data have supported the use of endopyelotomy for this indication in children, but current recommendations support its use only when the ureteral lumen is recognizable for cannulation [116]. Relative contraindications include a large collecting system, poor ipsilateral renal function, and the presence of anomalous crossing renal vessels [109, 117], but these also remain controversial [118]. Braga *et al*. recently compared success rates between retrograde endopyelotomy and redo pyeloplasty in 32 children who had failed primary pyeloplasty. With a mean follow-up of 47 and 33 months, respectively, endopyelotomy was only successful in 39% of patients, while redo pyeloplasty was successful in 100% of patients ($P = .002$). Despite a limited number of patients, narrowed ureteral segment greater than 10 mm, and age younger than 4 years were associated with a poor outcome with an endoscopic approach [119]. Due to the potential morbidity and technical difficulty of redo pyeloplasty, the only contemporary relative indication for endopyelotomy in children is for recurrent UPJO following failed pyeloplasty, and even then only in select cases.

Conclusions

Evolution of technique and miniaturization of instruments have changed the management of pediatric stone disease. However, despite encouraging results, concern remains regarding the safety of endourologic treatment in smaller patients and its subsequent effects on the growing kidney. While SWL is still considered first-line therapy for upper tract calculi of less than 1.5 cm, evidence is accumulating that URS may be more efficacious in treating upper tract stone disease in children. While PCNL remains the most effective technique for large upper tract stone burdens, there are now reports of laparoscopic and robot-assisted laparoscopic pyelolithotomy in major pediatric academic centers with extensive laparoscopic and robotic experience. Prospective randomized studies designed to evaluate the endourologic management of upper tract calculi in children are sorely needed, and until these data are available, individual surgeon experience is the most important factor in determining the appropriate treatment modality. Similar to endourologic management in the adult population, familiarity with the full spectrum of endourologic techniques facilitates a minimally invasive approach to the entire pediatric urinary tract.

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CHAPTER 66

Cost-Effective Strategies for Management of Renal and Ureteral Calculi

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Introduction

Nephrolithiasis is a common and costly disorder. Data from NHANES III (1988–1994) indicates a lifetime risk of stone disease in American adults of 5.2%, up from 3.2% in 1976–1980 [1]. Accordingly, in 2000 it was estimated that over US$2 billion was spent on the treatment of urolithiasis, a substantial increase from the US$1.37 billion spent in 1994, and almost certainly an underestimate. Indeed, the Urologic Diseases of America Project estimated that the average differential in annual expenditure for a privately insured individual between the ages of 18 and 64 years with or without a diagnosis of urolithiasis was US$4472 (US$7656 vs US$3184), a difference attributable to the cost of managing stone disease [2]. Furthermore, as the disease is most prevalent among individuals in their working years, it was estimated that among the 1% of working-age Americans who experienced a stone event in 2000, one-third of them each missed an average of 19 h of work due to this diagnosis [3]. These statistics underscore the substantial economic impact of nephrolithiasis on not only the individual, but also on the healthcare system and society.

Basics of cost analysis

With limited resources and numerous treatment options, physicians must be cognizant of the economic consequences of various treatment choices. Economic factors can impact availability of technology and feasibility of medication use to the extent that physicians need to consider both the cost and effectiveness of various treatment options. To understand cost analyses in the literature, the relevant language must first be clarified. The definition of "cost" varies according to whose perspective is being considered. If cost is considered from the patient's perspective, it refers to the amount they can expect to pay out-of-pocket for a given treatment, which in turn depends on the type of insurance, associated co-pay/deductible requirements, and employment status, since income may be lost during treatment. Consequently, cost from the patient perspective is highly variable and must be individualized. For example, the cost shouldered by an uninsured, working individual who must pay all of their own healthcare bills out-of-pocket will be vastly different from the cost for a person living within a free, nationalized healthcare system. Furthermore, the decision to initiate a long-term medical prophylactic program to prevent future stone formation has a different financial impact from a strategy of periodic emergency room visits and surgery to treat stones as they arise.

Quantifying the societal cost of healthcare-related to nephrolithiasis is likewise problematic. In countries with a national healthcare system, medical decision-making directly impacts the nation's budget. In other countries, such as the USA, programs such as Medicare or Medicaid are funded by the government to cover the healthcare needs of select groups of patients, partially tethering the economics of healthcare to overall budgetary concerns. Throughout the world, indirect economic consequences, such as lost wages due to illness impact

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society as a whole, although these indirect costs are difficult to quantify.

Most research into healthcare cost takes the perspective of the hospital, since hospital costs and expenditures are easier to define, even though they may vary somewhat from center to center and from country to country. These costs consist of a variety of cost centers, including the purchase and maintenance costs of capital equipment such as lithotripters, the cost of physician and other healthcare workers' labor, medications, and services and supplies utilized during hospitalization (i.e. room and board, pharmacy, radiology).

Of note, in any discussion about the financial implications of a treatment strategy, the terms "cost" and "charge" must be distinguished. "Cost" typically refers to the direct cost to the hospital to purchase an item or provide a service, whereas "charge" includes not only the direct cost of an item/service, but also the indirect cost associated with its supply, such as administration and marketing, and a defined profit margin. The ratio of cost to charge may vary between surgical procedures; e.g. a hospital may elect to exact a larger profit margin from one service than another despite a lower actual cost to the hospital. The overall charge is what appears on the bill, although its components are often difficult if not impossible to sort out. Since hospital billing statements are often the most accessible cost data, charges are unfortunately frequently used in cost analyses reported in cost literature. It should be apparent after this discussion that charge data are somewhat arbitrary and may not relate in a consistent way to actual cost. Nonetheless, cost data are not without flaw either, as the amoratization of capital equipment, cost of reusable equipment, and specific labor costs can be nebulous.

Furthermore comparing costs of treatment across countries with different healthcare systems can be problematic. For example, the difference in costs of common procedures such as ureteroscopy (URS) and shock-wave lithotripsy (SWL) are highly variable among countries and depend on both the cost of the capital and disposable equipment as well as the degree of subsidization [4, 5]. As such, cost based on one center's situation may not be applicable in another healthcare system. Consequently, cost analyses must be viewed in the context in which they are presented.

Finally, it is important to mention that cost is only one of a variety of outcomes that should be considered when making medical decisions. Other factors affecting outcomes such as stone characteristics, patient comorbidities and preferences, equipment availability, and surgeon preference and skill may, in some cases, outweigh cost concerns in the selection of a treatment strategy for nephrolithiasis. While cost analyses often take into account efficacy since retreatments can be costly, the most efficacious option may not be the least costly, particularly when considering observation as a treatment option.

Ureteral calculi

The treatment of ureteral calculi is comprised of several decision points: how to make the diagnosis, what measures are used to ascertain the need for surgical intervention, and how to determine the optimal surgical treatment modality. Each option along the decision tree has associated cost concerns that impact the overall cost of any treatment strategy.

Diagnosis

The cost of treating ureteral calculi begins with diagnosis. Historically, intravenous urography (IVU) was the gold standard among imaging modalities for the diagnosis of ureteral calculi. However, the introduction of helical computed tomography (CT) provided a faster, more accurate diagnostic tool for the evaluation of acute flank pain, with a sensitivity of 98% and a specificity of 95–100% [6, 7]. Although the cost of CT is higher than the cost of IVU, it was theorized that the higher capital equipment cost associated with CT would be offset by the additional cost of further imaging studies should IVU fail to make a diagnosis.

Several studies have analyzed the cost of CT versus IVU in the setting of acute flank pain. Pfister *et al.* performed a prospective, randomized trial (RCT) comparing nonenhanced CT and IVU for acute flank pain and found equivalent direct charges (310 Euro vs 309 Euro, respectively), but with the caveat that the indirect cost associated with CT was likely lower because examination time for CT was only about 25% as long as for IVU [8]. Eikefjord *et al.* found a greater cost differential between CT and IVU (32 Euro vs 117 Euro, respectively), with the bulk of the cost savings for CT attributed to lower personnel costs related to shorter examination time [6]. Other studies have shown cost savings or cost-equivalence for CT over IVU [7, 9] and further showed that CT has the additional advantage of more frequently diagnosing the source of the pain when ureteral calculi were ruled out (62% for CT vs 22% for IVU) [6]. Based on higher sensitivity and lower cost, CT has become the imaging modality of choice for the diagnosis of acute flank pain. In the future, cost studies may need to consider not only the acute cost associated with CT but any potential risks associated with greater radiation exposure that may result in additional future expense.

Urgent intervention

With the definitive diagnosis of a ureteral stone, the need for urgent intervention must be entertained based on the clinical setting. In the face of ureteral obstruction and suspected infection, urgent decompression of the collecting system is mandatory to prevent urosepsis and its sequelae. Both percutaneous nephrostomy and ureteral stent placement have been shown to be effective for temporary urinary diversion. The choice of optimal drainage modality for the obstructed kidney was addressed in two RCTs [10, 11]. Pearle *et al.* randomized 42 patients with obstruction and suspected infection due to ureteral calculi to either percutaneous nephrostomy or ureteral stent placement, and compared time to clinical improvement as well as cost [11]. Although the two modalities were equally efficacious with regard to the time to normalization of temperature and/or white blood count, percutaneous nephrostomy tube placement was the less costly of the two procedures (US$1137 vs US$2401, respectively), largely due to the use of general anesthesia in the operating room for stent placement. Mokhmalji *et al.* randomized 40 patients with hydronephrosis due to ureteral calculi, with or without signs of infection, to either nephrostomy or stent, and concluded that percutaneous nephrostomy was the superior drainage modality based on the need for less fluoroscopy time (10% vs 40% with >2 min, respectively), shorter time to definitive stone treatment (25% vs 50% with need for diversion at 2 weeks, respectively), and shorter duration of antibiotics (0% vs 64% requiring antibiotics for longer than 5 days, respectively) [10]. However, cost was not analyzed in this study.

An additional potential cost concern in favor of nephrostomy is the possibility of failed stent placement in some patients with obstructing stones. Percutaneous nephrostomy in the setting of obstruction and hydronephrosis is generally highly successful due to the large, dilated collecting system. Indeed, Mokhmalji *et al.* reported a 20% rate of failed stent placement in their series compared with no failed nephrostomies [10]. In contrast, Pearle *et al.* reported no unsuccessful stent placements but a single unsuccessful nephrostomy tube placement [11]. Although several series have reported rates of successful stent placement of approximately 80% [10, 11], stent failures will incur the additional cost of salvage nephrostomy.

Presuming equivalent efficacy for collecting system decompression in the acute setting of obstruction and infection, the choice of nephrostomy versus stent placement can be based on secondary factors such as cost, availability of an operating room or an interventional radiologist, location or size of the stone, and patient and physician preference.

Medical expulsive therapy

The likelihood of spontaneous passage of ureteral calculi depends on stone size, stone location, and ureteral anatomy [12, 13]. Spontaneous passage rates vary inversely with stone size and increase the more distally in the ureter the stone is located at the time of diagnosis [12]. A number of drugs have been shown to alter the natural history of ureteral calculi and to increase the likelihood of spontaneous passage, constituting so-called medical expulsive therapy (MET) [14].

Although MET has been shown to be efficacious in promoting stone passage, it is also associated with the additional cost of medication, even in those patients who are initially observed but ultimately require surgical intervention for their stones. Bensalah *et al.* performed a cost-effectiveness analysis to determine if MET was a cost-effective practice in patients with ureteral calculi [15]. They constructed a decision tree that compared the cost of each of two pathways of initial observation or surgical therapy. For each pathway, there is a potential for successful stone passage/treatment or for treatment failure thereby necessitating further intervention. Each of these pathways is associated with specific costs: the cost of medication, emergency room and office visits, hospitalization, radiographic imaging, surgery, and lost wages for time off work. Because patients who fail the primary treatment will additionally incur the cost of secondary treatment, the overall cost of a given treatment strategy is substantially impacted by the success rate of the primary treatment and is influenced by factors such as stone size and stone location. For example, observation alone is highly likely to be successful in a patient with a 2-mm distal ureteral calculus and therefore the additional cost of salvage URS is unlikely to be incurred.

For the model, they used data from the American Urological Association (AUA) Ureteral Stone Clinical Guidelines Panel, in which a meta-analysis of randomized MET trials showed that alpha-blockers provided a 29% absolute increase in rate of stone passage compared to placebo or no treatment [16]. Taking into account the success rates of MET from the meta-analysis and the success rates of spontaneous stone passage with observation alone from natural history studies and the control arms of MET RCTs, Bensalah *et al.* calculated a US$1132 cost advantage of MET over initial observation (US$1493 for MET vs US$2625 for observation alone) for the treatment of distal ureteral stones [15]. Indeed, because of the high cost of URS in the USA, MET was shown to be economically favorable even if MET was associated with only a 1% improvement in stone passage rates over observation alone. Since the cost of URS varies greatly among countries and healthcare systems but is uniformly quite high in the USA, the authors also concluded that MET was associated with cost savings over observation in several other countries as well.

Another American study by Brede *et al.* examined charges incurred by patients seen in the emergency department (ED) for acute ureteral stone events and evaluated the impact of MET over observation alone [17]. They took into consideration fees resulting from hospitalization, repeat visits to the ED, and surgery (all deemed "adverse events"), and found that use of MET decreased the rate of occurrence of adverse events by 24%, translating into a 29% decrease in cost compared to observation alone. Thus, MET, with its lower cost and substantial improvement in stone passage rates, is a cost-effective treatment strategy in patients with distal ureteral calculi of less than 1 cm in diameter, the group most thoroughly studied in RCTs. Whether this recommendation will hold true for patients with stones in other ureteral locations awaits further study. In patients without absolute indications for surgery it appears likely that short-term use of medication will be cost-effective even if it is only associated with a slight benefit in terms of efficacy because of the high cost of surgery.

Surgical intervention

Most ureteral calculi will pass spontaneously [16, 18]. However, for those stones that fail or are unlikely to pass based on size, location, or ureteral or patient anatomy, surgical intervention must be considered. The mainstays of treatment for ureteral stones are SWL and URS. The 2007 AUA Ureteral Stones Clinical Guidelines Panel stated that both SWL and URS are acceptable first-line treatment options for ureteral stones, but noted that URS was associated with a higher stone-free rate after a single procedure [16]. However, SWL and URS do differ with regard to cost for a variety of reasons, including differences in stone-free rates, complication rates, and cost of equipment. Furthermore, other factors besides cost influence the choice of surgical treatment, including stone characteristics, surgeon skill, and patient preference. Additionally, due to wide variations in cost parameters internationally, it is difficult to generalize conclusions drawn from one country to another.

Grasso *et al.* evaluated outcomes and cost in 112 patients treated with SWL or URS for ureteral stones, without stratifying patients according to stone location [19]. They found that while the cost of the initial treatment was comparable between the two modalities, the overall cost of SWL was substantially higher than the cost of URS because a greater number of patients in the SWL group required a secondary or auxiliary procedure (31% vs 3%, respectively). Parker *et al.* also found a cost advantage of US$1932 for URS over SWL for the initial treatment of patients with proximal ureteral stones [20]. The cost difference became even more pronounced (US$6205) when taking into consideration the cost of additional procedures, imaging, and office visits.

Several studies have examined the cost of treating particular subgroups of patients with ureteral calculi. Salem conducted a prospective, randomized trial of SWL versus URS for proximal ureteral calculi in Egypt, and compared the overall cost of treatment, including the cost of preoperative evaluation, surgery, secondary and auxiliary procedures, and emergency room and clinic visits [21]. Although URS as a procedure was more costly than SWL [3000 vs 2500 Egyptian pounds (EP)], overall cost favored URS (5700 EP for URS vs 6500 EP for SWL), because 35% of SWL patients required emergency room visits for renal colic at a mean cost of 1150 EP per patient. Wu *et al.* also compared the cost of treating patients in China with large (>1 cm) proximal ureteral calculi with URS or SWL and found that URS was less costly (US$953) than SWL (US$1401) [22].

One factor that seems to universally impact the cost of the procedure is the need for hospitalization. Although in the USA both URS and SWL are performed largely on an outpatient basis, in many other countries URS requires a hospital stay. A Dutch study by Bierkens *et al.* comparing SWL and URS for the treatment of middle and distal ureteral calculi found SWL to be less costly due to a substantially longer hospital stay for the URS patients, averaging 3 days [23]. Indeed, Anderson *et al.* found that URS was slightly less costly than SWL in their US hospital, but only if URS patients were treated as outpatients [24]. In a study of patients with distal ureteral stones in which all patients were hospitalized for at least one night, Kapoor *et al.* determined that URS cost 60% less than SWL, primarily due to the higher initial success rate [25].

Table 66.1 summarizes studies comparing the cost of URS and SWL for ureteral calculi. However, it is difficult to directly compare the various studies as there is no consensus in the literature regarding the specific factors that should be included in cost calculations and from whose perspective cost is determined. For example, all of the studies listed in Table 66.1 used charge, rather than cost data, and the charges comprising the total varied among studies. While all studies included charges for the primary surgical procedure, Bierkens *et al.* tallied only the surgeon/anesthesia fees, choosing not to include the cost of equipment/disposables [23]. Other studies included the cost of preoperative evaluation [21, 22, 25], while some presumed that these costs would be similar in both groups and therefore excluded them from analysis. Only two studies specifically evaluated and included the charges associated with complications, including emergency room care as well as unplanned hospital admissions or nephrostomy tube/ureteral stent placements related to obstruction [21, 25]. Finally, Bierkens *et al.* additionally

Table 66.1 Cost studies comparing ureteroscopy (URS) versus shock-wave lithotripsy (SWL) for the management of ureteral stones.

Study	Country	Stone location (n URS; SWL)	Single procedure stone-free rate URS[a] (n)	Single procedure stone-free rate SWL[a] (n)	2° Tx URS[b] (n)	2° Tx SWL (n)	Overall cost of URS[c] (in US dollars unless noted)	Overall cost of SWL[c] (in US dollars unless noted)
Grasso *et al.* [19]	USA	All (70; 42)	97% (3 months) (68)	62% (3 months) (26)	3% (2)	31% (13)	Not reported	Not reported
Parker *et al.* [20]	USA	Proximal (109; 111)	90.8% (99)	55% (61)	9% (10)	45% (50)	9378	15583
Salem [21]	Egypt	Proximal <1 cm (52; 58) >1 cm (48; 42)	100% (52) 88% (44)	80% (46) 60% (25)	0% (0) 8% (4)	21% (12) 40% (17)	5700 EP	6500 EP
Wu *et al.* [22]	China	Proximal (39; 41)	92% (36)	61% (25)	8% (3)	39% (16)	953	1401
Bierkens *et al.* [23][a]	Netherlands	Mid (25; 79) Distal (80; 44)	96% (24) 99% (79)	90% (17) 81% (36)	12% (NR) 7% (NR)	50% (NR) 50% (NR)	3150 3225	2376 1507
Anderson *et al.* [24]	USA	Distal (27, 22;[d] 27)	100% (27)	Lithostar 84% (n?) HM3 96% (26)	0% (0)	14% (3) 4% (1)	Inpatient 8544 Outpatient 6801 Avg 8263	HM3 8539
Kapoor *et al.* [25]	USA	Mid/distal (32; 20)	96.7% (31)	75% (15)	3% (1)	25% (5)	4568.47	7320.26

[a] Stone-free rate from initial procedure only, performed one time except in Bierkens *et al.*, where only stone-free rates after all primary procedures (either URS or SWL) were performed were reported.

[b] Does not include stent removal procedures.

[c] Definition of "overall cost" varied between papers in what was included but is based on charge data in all cases. See text for details.

[d] Two groups were treated with SWL: one using the Dornier HM3 (n = 27) and one using the Siemens Lithostar (n = 22).

2° Tx, secondary treatments, all surgeries performed after single procedure of primary treatment, including retreatments/salvage treatments with either SWL or URS as well as salvage open or PCNL procedures.

factored in a “disability cost,” estimated at US$60/day, in an attempt to account for differences in lost work productivity related to surgical treatment of a ureteral stone. This cost was accrued for each day spent in the hospital, undergoing a procedure, or attending an office visit [23].

To account for differences in cost and success rates for the two procedures from institution to institution, decision analysis models provide theoretical tools that, through a series of assumptions about treatment choices, outcomes, and cost, can be used to compare the cost of different treatments. Wolf *et al.* developed a model comparing SWL and URS for the treatment of distal ureteral calculi in which they assumed success rates of 92% for URS and 74% for SWL based on available literature [26]. By their calculation, the cost of SWL would have to drop by US$1107 to be equivalent with URS. Lotan *et al.* used a decision-tree analysis (Figure 66.1) to compare observation, SWL, and URS for the treatment of patients with ureteral stones, and additionally stratified patients according to stone location (proximal, middle, or distal ureter). For each stone location, they determined that observation was the least costly approach, provided the cost of missed work and additional treatment or evaluation (such as emergency room visits) did not exceed US$456 [27]. Comparing the two surgical treatment modalities, URS was less costly than SWL for all ureteral locations by US$1440, US$1670, or US$1750 for patients with proximal, middle, and distal ureteral stones, respectively, primarily due to the high cost of purchasing and maintaining a lithotripter, which was factored into the analysis. Two-way sensitivity analyses were performed for URS and SWL at different success rates and costs to determine the overall cost of treatment based on the model (Table 66.2). This analysis allowed the creation of a universal table by which the least costly treatment modality within a large range of success rates (50–95%) and costs (US$2000–5000) can be identified, thereby making the table generalizable to any hospital or country.

As long as lithotripters cost more than ureteroscopes, the lack of greater efficacy of SWL makes URS the more cost-effective in managing ureteral and most renal stones (see below). Even the fragility of ureteroscopes, with added repair costs, is balanced by the high annual maintenance costs of the lithotripter.

Renal calculi

The cost of treating renal calculi has not been scrutinized as thoroughly as that for ureteral calculi. However, the cost of treating particular subgroups of patients with renal calculi, such as staghorn and lower pole calyceal calculi, has been addressed. In general, the most commonly used treatment modalities for renal calculi are URS, SWL, and percutaneous nephrolithotomy (PCNL).

Staghorn calculi

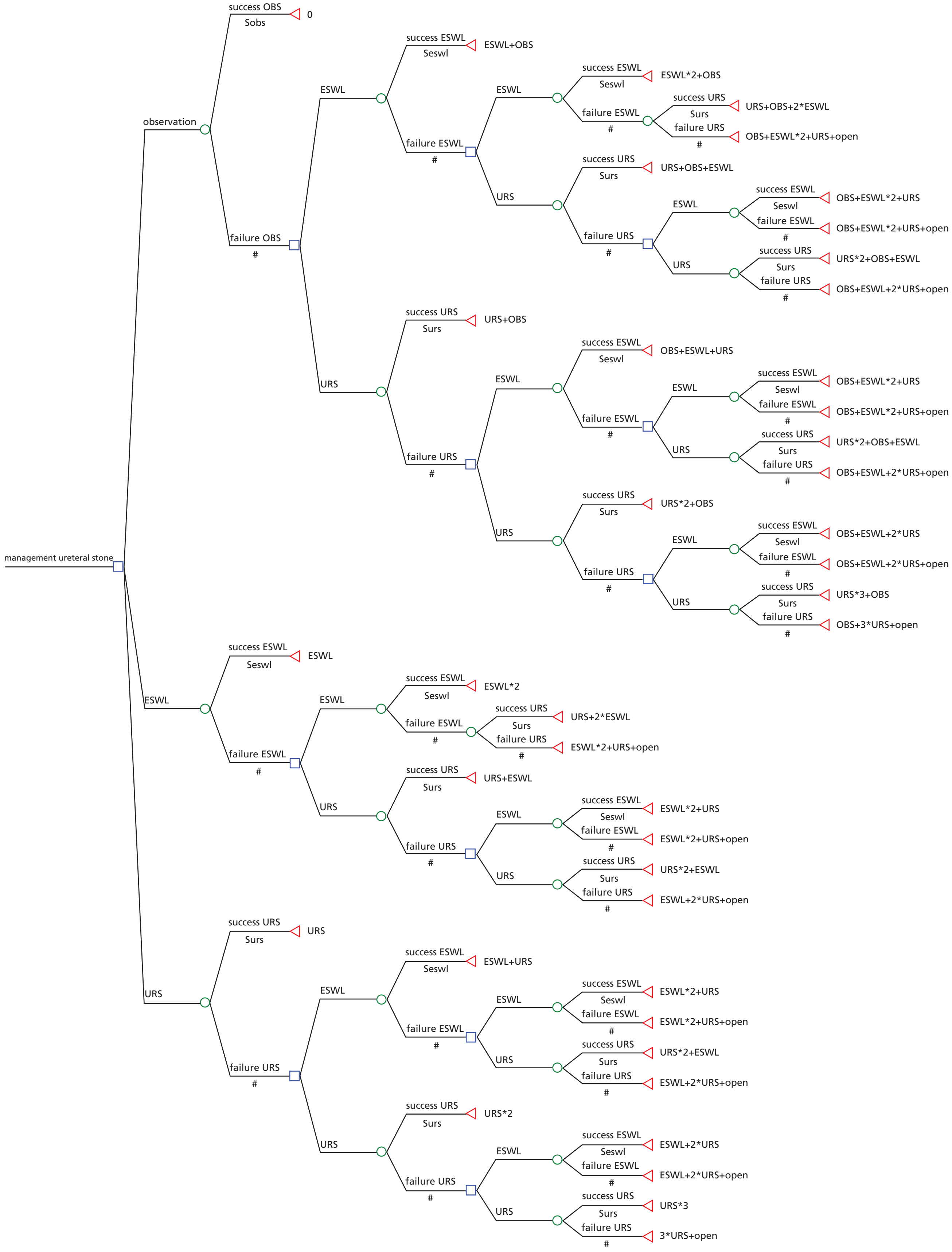
The AUA Clinical Guidelines Panel on Staghorn Calculi recently updated their 1994 Guidelines [28] and recommended PCNL monotherapy as the optimal treatment modality for staghorn calculi [29]. The panel emphasized the liberal use of flexible nephroscopy to achieve a stone-free state after initial PCNL, which is a departure from the 1994 Panel recommendation of combination therapy (PCNL/SWL) as first-line treatment. However, there are a few limited clinical circumstances where SWL monotherapy may be acceptable for the treatment of staghorn calculi, such as a small volume stone in a nondilated collecting system [30]. However, despite few clinical indications, SWL monotherapy continues to be used by some practitioners for the management of unselected patients with staghorn stones.

Chandhoke used a model to determine the “cost-effectiveness index” for different treatments for staghorn calculi (i.e. the average cost of rendering one patient stone free), defined as the treatment cost divided by the stone-free rate, plus cost of complications multiplied by the complication rate [31]. Using *charge* data from his own institution and efficacy and complication rates from the 1994 AUA Staghorn Calculi Guidelines, he formulated a decision analysis evaluating SWL, PCNL, and combination therapy (PCNL/SWL). He calculated that SWL monotherapy was the least cost-effective modality followed by combination therapy, with PCNL monotherapy the most cost-effective, although the actual cost-effectiveness index varied according to the type of secondary treatment utilized (percutaneous-based vs URS). Assuming URS as the secondary procedure, cost-effectiveness indices were US$52 251 for SWL monotherapy, US$48 095 for combination therapy, and US$36 672 for PCNL monotherapy. He further stratified patients by stone volume, according to the classification scheme used by Lam *et al* [30], to compare the cost-effectiveness of SWL monotherapy and combination therapy, and found that the two modalities were cost-equivalent when the stone burden was less than 500 mm^2 but that combination therapy was more cost-effective for stones larger than 500 mm^2.

Based on these studies, PCNL monotherapy is the preferred initial modality for the management of staghorn calculi, based on superior efficacy, efficiency, and cost-effectiveness.

Nonstaghorn renal calculi

For nonstaghorn renal calculi, SWL has long been the treatment of choice, due to high stone-free rates and low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OBS+ESWL+2*URS+open
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URS*2+OBS
URS
success ESWL
Seswl
OBS+ESWL+2*URS
ESWL
failure ESWL
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OBS+ESWL+2*URS+open
management ureteral stone
failure URS
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success URS
Surs
URS*3+OBS
URS
failure URS
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OBS+3*URS+open
success ESWL
Seswl
ESWL
success ESWL
Seswl
ESWL*2
ESWL
ESWL
success URS
Surs
URS+2*ESWL
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ESWL*2+URS+open
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URS+ESWL
URS
success ESWL
Seswl
ESWL*2+URS
ESWL
failure ESWL
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ESWL*2+URS+open
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URS*2+ESWL
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ESWL+2*URS+open
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ESWL+URS
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URS*2+ESWL
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ESWL+2*URS+open
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ESWL+2*URS+open
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Figure 66.1 Decision-tree model of three initial treatment options for ureteral calculi, including ureteroscopy (URS), extracorporeal shock-wave lithotripsy (ESWL), and observation (OBS), and secondary, tertiary, and quaternary treatment options after failure. For each initial treatment strategy, there are possible outcomes, each of which can lead to further outcomes. Each alternative outcome has cost consequences, such that the total cost of an initial treatment strategy is the sum of the costs of each individual outcome along the pathway. Seswl, success of SWL; Sobs, success of observation; Surs, success of URS; Open, open salvage procedure (reproduced from Lotan *et al.* [27], with permission from Elsevier).

Table 66.2 Cost comparison for ureteroscopy (URS) and shock-wave lithotripsy (SWL) at varying costs and success rates. At each interval results are presented in the order of SWL, URS; shaded areas represent cost advantage for ureteroscopy (reproduced from Lotan *et al*. [27], with permission from Elsevier).

		Shock-Wave Lithotripsy Success Rates															
Ureteroscopy Success Rates	Ureteroscopy Cost	0.50	0.50	0.50	0.50	0.65	0.65	0.65	0.65	0.80	0.80	0.80	0.80	0.95	0.95	0.95	0.95
		Shock-Wave Lithotripsy Cost															
		2000	3000	4000	5000	2000	3000	4000	5000	2000	3000	4000	5000	2000	3000	4000	5000
0.50	2000	4500	5500	6500	7500	3435	4715	5750	6750	2640	3840	4960	6000	2115	3165	4210	5235
		4500	4500	4500	4500	3840	4450	4500	4500	3360	3960	4400	4500	3060	3585	4100	4350
0.50	3000	4750	6250	7250	8250	3558	4908	6240	7275	2680	3880	5080	6260	2118	3168	4218	5268
		5500	6250	6250	6250	4840	5515	6190	6250	4360	4960	5560	6150	4060	4585	5110	5635
0.50	4000	5000	6500	8000	9000	3680	5030	6380	7730	2720	3920	5120	6320	2120	3170	4220	5270
		6500	7250	8000	8000	5840	6515	7190	7865	5360	5960	6560	7160	5060	5585	6110	6635
0.50	5000	5250	6750	8250	9750	3803	5153	6503	7853	2760	3960	5160	6360	2123	3173	4223	5273
		7500	8250	9000	9750	6840	7515	8190	8865	6360	6960	7560	8160	6060	6585	7110	7635
0.65	2000	3840	4840	5840	6840	3288	4288	5288	6288	2592	3722	4736	5736	2112	3160	4177	5184
		3288	3288	3288	3288	3288	3288	3288	3288	2952	3264	3288	3288	2742	3110	3239	3288
0.65	3000	4450	5515	6515	7515	3411	4761	5761	6761	2632	3832	4992	6006	2115	3165	4215	5245
		4715	4761	4761	4761	4288	4761	4761	4761	3952	4372	4736	4761	3742	4110	4477	4712
0.65	4000	4700	6190	7190	8190	3533	4883	6233	7233	2672	3872	5072	6262	2117	3167	4217	5267
		5750	6233	6233	6233	5288	5761	6233	6233	4952	5372	5792	6209	4742	5110	5477	5845
0.65	5000	4950	6450	7865	8865	3656	5006	6356	7706	2712	3912	5112	6312	2120	3170	4220	5270
		6750	7275	7706	7706	6288	6761	7233	7706	5952	6372	6792	7212	5742	6110	6477	6845
0.80	2000	3360	4360	5360	6360	2952	3952	4952	5952	2544	3544	4544	5544	2109	3134	4136	5136
		2544	2544	2544	2544	2544	2544	2544	2544	2544	2544	2544	2544	2424	2536	2544	2544
0.80	3000	3960	4960	5960	6960	3264	4372	5372	6372	2584	3784	4784	5784	2112	3162	4194	5196
		3784	3784	3784	3784	3722	3784	3784	3784	3544	3784	3784	3784	3424	3634	3776	3784
0.80	4000	4400	5560	6560	7560	3386	4736	5792	6792	2624	3824	5024	6024	2114	3164	4214	5254
		4960	5024	5024	5024	4736	4992	5024	5024	4544	4784	5024	5024	4424	4634	4844	5016
0.80	5000	4650	6150	7160	8160	3509	4859	6209	7212	2664	3864	5064	6264	2117	3167	4217	5267
		6000	6260	6264	6264	5736	6006	6262	6264	5544	5784	6024	6264	5424	5634	5844	6054
0.95	2000	3060	4060	5060	6060	2742	3742	4742	5742	2424	3424	4424	5424	2106	3106	4106	5106
		2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106	2106
0.95	3000	3585	4585	5585	6585	3110	4110	5110	6110	2536	3634	4634	5634	2109	3159	4159	5159
		3159	3159	3159	3159	3159	3159	3159	3159	3134	3159	3159	3159	3106	3159	3159	3159
0.95	4000	4100	5110	6110	7110	3239	4477	5477	6477	2576	3776	4844	5844	2111	3161	4211	5211
		4210	4211	4211	4211	4177	4211	4211	4211	4136	4194	4211	4211	4106	4159	4211	4211
0.95	5000	4350	5635	6635	7635	3362	4712	5845	6845	2616	3816	5016	6054	2114	3164	4214	5264
		5235	5264	5264	5264	5184	5245	5264	5264	5136	5196	5254	5264	5106	5159	5211	5264

morbidity. Indeed, SWL remains the only noninvasive surgical treatment for renal and ureteral calculi. However, it is known that SWL stone-free rates are inversely proportional to stone size, and that retreatment and complications rates vary directly with stone size. Consequently, alternative treatments such as PCNL and URS have been considered for the treatment of large renal calculi. No analyses have evaluated the cost-effectiveness of various treatment modalities for the management of small-to-moderate renal calculi, likely because it is easy to justify SWL on the basis of its noninvasiveness and effectiveness for stones of this size. However, Hyams and Shah compared the cost-effectiveness of URS versus PCNL for the management of patients with large (2–3 cm) stones in a retrospective review of 39 patients [32]. Taking into account the number of primary procedures (intended treatment modality) as well as the need for secondary procedures (to further achieve a stone-free state), they calculated the cost difference between the two modalities using Medicare reimbursement rates. They concluded that, despite a substantially lower stone-free rate with URS compared with PCNL (47% vs 89%, respectively, $P = .01$), URS was ultimately less costly than PCNL (US$6,675 vs US$19 845, respectively, $P = .0001$). The cost difference between the two treatment modalities was due in part to the difference in the need for repeat procedures, which were required in 55% of the PCNL group (11 of 20) but only 5% of the URS group (1 of 19). Of note, however, the URS patients had a higher residual stone rate, suggesting that the authors were less likely to perform second-look URS than second-look PCNL. Also of importance, stone-free status in this series was evaluated with kidneys, ureters, and bladder (KUB) scan (before 2007) or CT (after 2007) for PCNL patients, while URS patients were evaluated with renal ultrasound with or without KUB, further limiting the validity of comparison, and artificially favoring URS.

This analysis highlights the difference between a *cost comparison*, which identifies the less costly procedure, versus a *cost-effectiveness analysis*, which takes into account not only cost but also efficacy. For example, if procedure A costs US$1000 and is 100% effective and procedure B costs US$500 but is only 25% effective, then procedure B would be less costly in a cost comparison study but would fare less well in a cost-effectiveness study. It is also important to distinguish *cost* and *compensation*, which unfortunately are frequently disparate in medicine. Some procedures yield high profit margins while others are loss leaders. As such, the use of reimbursement rates as a measure of "cost" is inappropriate, since they reflect not the sum of the resources utilized by the hospital, but rather the amount the hospital will collect for a procedure. Medicare reimbursement schedules are an artificially set rate of compensation that is not necessarily linked to the actual cost of materials and personnel for hospitals. Furthermore, the ratio between the actual cost of a procedure and the reimbursement from Medicare is not fixed, which can thereby create inaccuracies when using this type of data to compare different procedures.

Lower pole calyceal calculi

Another area of controversy in the treatment of renal calculi is the optimal management of lower pole renal calculi. Albala *et al.*, representing the Lower Pole Stone Study Group, reported the results of a prospective, randomized clinical trial comparing SWL and PCNL for the management of isolated lower pole stones [33]. They found superior overall stone-free rates for PCNL versus SWL (95% vs 37%, respectively), with more pronounced differences between the two modalities evident with increasing stone size. May and Chandhoke conducted a cost analysis similar to Chandhoke *et al.*'s analysis of staghorn calculi (see above), using charge date from their own institution, and published success and complication rates. According to their analysis, despite lower initial success rates, SWL was more cost-effective than PCNL for the management of patients with lower pole stones of less than 2 cm, while PCNL was more cost-effective for patients with stones greater than 2 cm [34].

Further analyses of treatment modalities for lower pole calyceal stones were conducted by the Lower Pole Stone Study Group, which subsequently incorporated URS into its treatment algorithm. In an RCT comparing SWL and URS for the treatment of patients with lower pole stones of 1 cm or less, it found that stone-free rates were not statistically significantly different between the two treatment modalities (35% vs 50%), although secondary parameters tended to favor SWL [35]. For lower pole stones between 1 and 2.5 cm, patients were randomized to URS or PCNL since SWL outcomes had previously been shown to be unacceptable for stones in this size range. In this group of 42 patients, PCNL stone-free rates were higher than URS (71% vs 37%, $P < .05$), and although hospital length of stay was shorter for URS than PCNL, overall convalescence time was no different between the two groups [36]. Unfortunately, there are no published cost-effectiveness analyses based on these RCTs.

Cost factors for percutaneous nephrolithotomy

PCNL has become the treatment of choice for large and/or complex renal calculi based on high stone-free rates and acceptable morbidity. However, there are patient factors and procedural choices in the percutaneous management of renal calculi that impact the overall cost of the procedure. In order to perform the procedure in a cost-effective manner, it is critical to understand the factors that most prominently impact cost so as to target those areas for possible cost-reducing modifications. Bagrodia *et al.* retrospectively reviewed hospital cost (not charge) information from their hospital billing department for 179 patients who underwent PCNL, and then performed univariate and multivariate analyses to determine the most important predictors contributing to cost [37]. On univariate analysis, preoperative urinary infection, use of allopurinol, and stone size were associated with higher cost; however, only stone size proved to be an independent predictor of higher cost on multivariate analyses. On further analysis, the impact of stone size seemed to be primarily related to the increased need for second-look flexible nephroscopy procedures in patients with larger stone burdens. Of note, factors that did not predict cost were patient age, comorbidities, and obesity.

A number of investigators have shown that bilateral simultaneous PCNL can be performed safely and effectively [38–40]. Bagrodia *et al.* compared the cost-effectiveness of simultaneous bilateral PCNL (SB-PCNL) with staged bilateral PCNL [41]. In this study, the authors used actual cost information obtained from their hospital billing department for patients undergoing SB-PCNL and for patients undergoing unilateral PCNL with current procedural terminology (CPT) codes that were matched to a group of actual patients undergoing SB-PCNL. The authors chose to create a theoretical cost for staged bilateral PCNL based on comparable CPT codes matched with the SB-PCNL group so as to prevent a selection bias against the patients treated in a staged fashion, which in their practice typically included only those with very large bilateral staghorn calculi. SB-PCNL was associated with a cost saving of US$4374–5126 compared to staged PCNL, depending on the combination of CPT codes used for the two sides (50080 for <2-cm stones, 50081 for >2-cm stones). Cost savings in the SB-PCNL procedures were attributed to a variety of factors, including decreased overall operating room equipment costs (i.e. much of the same equipment could be reused for the second renal unit during SB-PCNL), shorter overall operating room time, and fewer imaging studies since both sides could be imaged simultaneously in the SB-PCNL group. In addition, they also found that SB-PCNL procedures were not associated with a longer hospital stay than unilateral PCNL, thus generating significant cost savings for the hospital and insurer. It is noteworthy that differences in surgeon fees between staged and simultaneous bilateral PCNL, however, favor staged bilateral PCNL, which may discourage practitioners from performing an overall less costly procedure (SB-PCNL) that is beneficial to patients.

In an attempt to decrease the morbidity of PCNL, some investigators have advocated the use of the so-called "mini-perc" procedure, whereby a smaller nephrostomy tract is created in the hope of reducing blood loss, renal damage, and postoperative pain [42, 43]. Although this procedure has not been widely accepted because the advantages have proven to be more theoretical than real [44], Feng *et al.* compared the cost of mini-perc using a 26F working sheath with standard PCNL using a 34F sheath [45]. Using hospital billing data, they determined that the cost of mini-perc was equivalent to that of standard PCNL. However, "tubeless" PCNL, in which an internal double pigtail ureteral stent is left in place *in lieu* of a nephrostomy tube to drain the kidney postoperatively, proved to be less costly than either standard PCNL or mini-perc (US$5562 for tubeless PCNL compared with US$7555 for standard PCNL and US$6565 for mini-perc). Of note, however, since this was a nonrandomized study, selection bias likely contributed to the choice of "tubeless", mini-perc, and standard PCNL, which could impact outcomes and cost.

One of the most important determinants of the overall cost of PCNL is the need for second-look flexible nephroscopy to remove residual fragments. While the goal of any surgical stone procedure is to completely remove all stone material, in practical terms this is achievable to a greater or lesser degree depending on the procedure. With the introduction of SWL, the concept of "stone free" became relative, and leaving behind small residual fragments was considered acceptable because of the noninvasive nature of the procedure. Because PCNL provides for manual retrieval of all stone fragments through a hole in the kidney, residual fragments are more readily addressed and leaving them behind is considered less acceptable.

A number of investigators evaluating the fate of residual fragments after SWL [46–50] and PCNL [51] have concluded that even small (<4 mm) residual fragments place patients at risk for future stone events. Although the cost of treating versus observing residual fragments after SWL has not been addressed, Raman *et al.* created a decision-tree model to evaluate the cost-effectiveness of second-look flexible nephroscopy for residual stones after PCNL [52]. Using Kaplan–Meir estimates to determine the likelihood of occurrence of a stone-related event, these authors previously determined that patients with fragments of greater than 2 mm in size had estimated 3- and 5-year survival rates (where survival indicates freedom from a stone-related event) of 56% and 33%, respectively, compared with 87% and 65%, respectively, for patients with residual fragments of 2 mm or smaller ($P = .04$) [51]. They constructed an algorithm to indicate the possible pathways a patient with residual stones could follow, along with the likelihood of each

Table 66.3 Two-way sensitivity analysis evaluating cost-effectiveness for second-look flexible nephroscopy for residual fragments (RFs) after percutaneous nephrolithotomy. Shaded areas indicate permutations where incurred RF costs are within US$100 of or greater than US$2475 fixed cost of second-look flexible nephroscopy (reproduced from Raman *et al*. [52], with permission from Elsevier).

Likelihood of requiring surgery for RF (%)											
100%	$0	$701	$1402	$2103	$2804	$3505	$4206	$4907	$5608	$6309	$7010
90%	$0	$639	$1279	$1918	$2557	$3197	$3836	$4475	$5115	$5754	$6393
80%	$0	$578	$1155	$1733	$2310	$2888	$3466	$4043	$4621	$5198	$5776
70%	$0	$516	$1032	$1548	$2063	$2579	$3095	$3611	$4127	$4643	$5159
60%	$0	$454	$908	$1362	$1817	$2271	$2725	$3179	$3633	$4087	$4541
50%	$0	$392	$785	$1177	$1570	$1962	$2355	$2747	$3139	$3532	$3924
40%	$0	$331	$661	$992	$1323	$1653	$1984	$2315	$2646	$2976	$3307
30%	$0	$269	$538	$807	$1076	$1345	$1614	$1883	$2152	$2421	$2690
20%	$0	$207	$414	$622	$829	$1036	$1243	$1451	$1658	$1865	$2072
10%	$0	$146	$291	$437	$582	$728	$873	$1019	$1164	$1310	$1455
0%	$0	$84	$168	$251	$335	$419	$503	$587	$670	$754	$838
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Likelihood of symptomatic stone event (%)

event. For the model, they used data from the literature on the natural history of residual fragments after SWL and PCNL in combination with cost data from their own institution regarding hospitalization, medications, lost wages, emergency room visits, and secondary surgeries/procedures. They determined that for residual fragments of 4 mm or smaller, a strategy of observation over second-look flexible nephroscopy was more cost-effective; on the other hand, for patients with residual fragments larger than 4 mm, second-look flexible nephroscopy was a cost-effective approach. Two-way sensitivity analysis, by which the likelihood of successful conservative management of residual fragments and the likelihood of a symptomatic stone event are varied over a range of possibilities, is shown in Table 66.3, which allows the cost-effectiveness of second-look flexible nephroscopy for a given set of outcome parameters to be determined.

Combining information from the natural history of residual stones after PCNL and cost data from the cost-effectiveness model, it appears that observation is a reasonable strategy in patients with residual fragments after PCNL of 2 mm or smaller, and second-look flexible nephroscopy is indicated in patients with residual fragments larger than 4 mm. For patients with residual fragments of 2–4 mm, if observation is considered, it is at the expense of a higher likelihood of experiencing a stone-related event.

There is a distinct need for more prospective studies evaluating the cost-effectiveness of URS, SWL, and PCNL for the treatment of renal calculi. While SWL is noninvasive and associated with low morbidity, the higher likelihood of secondary procedures adds an additional incremental cost compared to some other more efficacious modalities. Likewise, while improvements in ureteroscope design and the use of ureteral access sheaths has expanded the indications for URS and increased its use for large-volume renal stones, the ability to manage larger stone burdens ureteroscopically comes with the added cost of longer operative times. Finally, PCNL is the most efficacious procedure with regard to stone-free rates, but the associated hospital stay and higher complication rate make this modality costly, albeit in many circumstances cost-effective. Future studies need to take into account both stone location and stone size for determining the most cost-effective approach among these treatment modalities for the management of patients with renal calculi.

Medical evaluation and management

Given the high rate of recurrence of nephrolithiasis, a medical prophylactic program to reduce the likelihood of recurrent stones seems desirable. Indeed, a variety of medical treatments has been shown to decrease stone recurrence compared to no treatment [53]. However, drug treatments can be costly and may be associated with side effects that themselves reduce quality of life. Dietary measures alone have also shown effectiveness in reducing stone recurrence without additional cost, but to a lesser extent than drug therapy and at the expense of lifestyle changes. Furthermore, not every recurrent stone becomes symptomatic or requires treatment. Therefore, the benefit of preventing recurrent stones with medication or dietary modification must be weighed against the cost of treatment and the risk of side effects or the inconvenience of making a lifestyle change. Because of these conflicting outcomes, several authors have attempted to investigate the economic consequences of these varied approaches.

Parks and Coe compared rates of stone occurrence before and after the initiation of medical therapy, and calculated the cost savings of metabolic evaluation and medical treatment [54]. Upon entry into their stone clinic, patients were extensively evaluated with blood and urine studies and then counseled on dietary measures aimed at minimizing urinary stone risk factors. Additionally, select patients were prescribed medications such as thiazides, allopurinol, and potassium citrate, according to their metabolic background. With this diagnostic and treatment approach, the authors reported a stone remission rate of 83%. By applying this remission rate, along with estimates regarding the cost of surgical procedures, rates of stone passage events, and need for hospitalization, they estimated that their medical prophylactic regimen resulted in cost savings averaging US$1162–3162/patient/year. Of note, however, there was no true control group in this study, and pretreatment stone occurrence rates were based on patient recall, which is subject to bias. Furthermore, the "control" group did not systematically incorporate dietary measures, which have been shown to reduce recurrence rates [55–57], until after entry into the stone clinic. Therefore, the effectiveness and cost savings attributed to medical therapy in this study are likely overestimated.

Because patients differ in the aggressiveness of their stone disease, it is likely that the initiation of medical therapy may be efficacious and cost-effective in some, while dietary management alone may be sufficient in less aggressive or first-time stone formers without significant risk factors. Chandhoke used a cost model to determine the stone recurrence rate at which medical therapy becomes cost-effective [5]. For the model, he assumed that all recurrent stones became symptomatic and required either an emergency room visit or surgery. Additionally, he assumed a limited metabolic evaluation consisting of an office visit, two 24-h urine collections, imaging studies at 6-month intervals, and drug therapy distributed according to a published study. According to the model, at a recurrence rate of 0.3–4.0 stones/year, the cost of medical evaluation and treatment becomes equivalent to the cost of conservative therapy.

This type of more advanced analysis allows stratification of patients according to the aggressiveness of their disease, but was limited in that it evaluated only one strategy of metabolic evaluation and treatment and it likely overestimated the probability that a recurrent stone will become symptomatic or require treatment, thereby increasing the cost of conservative therapy.

Lotan *et al*. performed a more comprehensive cost-effectiveness analysis using a decision-tree model to compare the costs of six medical treatment strategies: dietary measures alone (conservative), empiric drug treatment (empiric), or directed drug therapy based on simple (SMEM) or comprehensive (CMEM) metabolic evaluation with either all patients receiving drug therapy (SMEM or CMEM) or only those patients with demonstrable metabolic abnormalities receiving drugs (modified SMEM and modified CMEM) [58]. The model took into account accrual of cost for evaluation, medications, emergency treatment, and surgical management for recurrent stones.

For first-time stone formers, conservative therapy was the most cost-effective strategy, resulting in a stone recurrence rate of one episode every 14 years (Table 66.4). For recurrent stone formers, conservative therapy was still the least costly approach, but it was associated with an unacceptably high recurrence rate of 0.3 stones/patient/year. The four drug treatment strategies were all more costly than conservative treatment (US$885–1187/year vs US$258/year for the conservative approach), but drug therapy further reduced recurrence rates by 60–86% over dietary therapy. A strategy of modified medical evaluation and management by which all patients received drug therapy after a limited evaluation (modified SMEM) was marginally more effective than empiric therapy and slightly more costly. Comprehensive evaluation and targeted medical therapy had equivalent or greater cost with little or no improvement in efficacy over empiric or modified SMEM.

Treatment strategies in which all patients received medication, regardless of 24-h urine findings, significantly improved recurrence rates (by up to 60%) over strategies where only patients with a metabolic abnormality were prescribed drugs. Furthermore, since comprehensive medical evaluation and management significantly increased the cost of treatment without added efficacy, either empiric therapy or a modified SMEM in which all patients received drug therapy was recommended. Interestingly, since conservative therapy (the least costly approach) was associated with an unacceptably high recurrence rate, this model demonstrated the practical cost-effectiveness of treating *all* recurrent stone formers with medication despite the relatively high cost of drugs, due to the associated significant reduction in recurrence rates. Now that potassium citrate is available in generic form, the cost-effectiveness threshold for medical therapy should be further lowered.

Table 66.4 Cost of medical therapy model summary and treatment outcomes (modified from Lotan *et al.* [58], with permission from Elsevier).

		Medical treatment			First-time stone formers		Recurrent stone formers	
Strategy	Evaluation	For hypercalciuria (% of patients)	For other metabolic causes (% of patients)	For no metabolic abnormality (% of patients)	Stone formation rate (stones/ patient/year)	Model cost (US$/year)	Stone formation rate (stones/ patient/year)	Model cost (US$/year)
Conservative	None	No drug	No drug	No drug	0.070	133	0.300	258
Empiric	None	K-Cit	K-Cit	K-Cit	0.013	966	0.057	990
Modified SMEM	Simplified	Tz + K-Cit (35)	K-Cit (35)	K-Cit (30)	0.011	1085	0.048	1104
SMEM	Simplified	Tz + K-Cit (35)	K-Cit (35)	No drug	0.028	835	0.120	885
Modified CMEM	Detailed	Tz + K-Cit (60)	K-Cit (30)	K-Cit (10)	0.009	1170	0.041	1187
CMEM	Detailed	Tz + K-Cit (60)	K-Cit (30)	No drug (10)	0.015	1087	0.065	1114

SMEM, simplified metabolic evaluation and management; CMEM, complete metabolic evaluation and management; Tz, thiazide; K-Cit, potassium citrate.

The advantage of this decision-tree model is that the cost-effectiveness of any medication can be determined by inputting its associated risk reduction and cost, and evaluating it using any of the six metabolic evaluation and treatment strategies.

Because of differences in healthcare systems, there is significant disparity in the cost of stone management worldwide. As such, comparison of treatment costs from one country to the next may not be meaningful [5]. Lotan *et al.* utilized a decision-tree model to evaluate the cost-effectiveness of medical evaluation and treatment strategies in a variety of healthcare systems [4]. Using data derived from a published international cost survey [5] and limiting the treatment arms to conservative therapy, empiric treatment, and comprehensive metabolic evaluation with targeted medical therapy in those found to have a metabolic abnormality, they used the model to determine the most cost-effective strategy in countries for which they had cost data. Conservative therapy based on dietary therapy alone was the most cost-effective strategy in first-time stone formers in all 10 countries. For recurrent stone formers, the most cost-effective strategy in all countries except the UK was conservative therapy, followed by empiric therapy and then directed medical therapy. In the UK, where the low cost of drug therapy is estimated at only US$29/patient/year, empiric therapy was the least costly strategy. Likewise, in other countries with relatively low medication costs, like Turkey and Switzerland, the cost difference between conservative and empiric therapy was marginal, although empiric therapy was associated with a significant improvement in efficacy. According to two-way sensitivity analysis, more than one stone episode/year would be required to render empiric therapy cost superior to conservative treatment in all analyzed countries except the UK and Switzerland. In countries like the USA where drugs costs are high, conservative therapy offered an even greater cost advantage. In their model, since there was little difference in efficacy between targeted and empiric medical therapy, the use of metabolic evaluation to direct medical therapy did not prove to be cost-effective in any of the countries studied.

Several European studies have concluded that medical therapy is cost-effective in their respective countries. Using medication costs of 220 Euros/year and a cost/stone episode of 2500 Euros in Sweden, Tiselius calculated that with an initial stone recurrence rate of 0.3 stones/patient/year, a medication that reduced stone recurrence rates by 50% would result in a cost savings of 375 Euros/patient/year [59]. Strohmaier and Hörmann, presuming a higher recurrence rate of 50% per year, found that a 40% risk reduction associated with medical therapy would result in yearly savings of 333.1 million DM for the German healthcare system [60].

It is clear from these international cost analyses that differences in the cost of medication and surgery across healthcare systems, largely based on subsidization, are responsible for differences in the cost-effectiveness of medical management treatment strategies. When medication costs are regulated or subsidized, the low cost of medication favors drug therapy. On the other hand, when the cost of medications is high, the relatively infrequent need for surgery to treat stone recurrences and the fixed reimbursement for surgical procedures favor a conservative approach.

Conclusions

Careful cost analyses are the key to developing cost-effective treatment strategies. However, cost analyses are only as accurate as the cost data used to derive them and they are only useful in the context of efficacy and efficiency. Consequently, cost-effectiveness models, which take into account not only cost but also efficacy, are invaluable for comparing different treatment strategies and for comparing treatments in different institutions or healthcare systems. However, even cost-effectiveness models are only as valuable as the assumptions and cost data inputted into them and must be carefully scrutinized. Their advantage over cost analyses is that they can be applied to any institution or country by changing the variables, such as success rates or cost. While determination of cost-effective practices is invaluable at a societal level, we must not lose sight of the impact of treatment decisions on the individual. The experience of passing a stone in an individual patient cannot be accurately or fairly described in dollars alone; nor is cost the only factor that should be considered when determining optimal treatment strategy. Thus in many situations, a treatment decision is chosen to maximize efficacy or another outcome (such as stone recurrence rate) despite its higher cost.

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CHAPTER 67

Long-Term Stenting of the Ureter

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Introduction

Ureteral stents are widely used in urologic clinical practice. The efficacy of ureteral stents in the management of various urologic conditions causing upper urinary tract obstruction has been extensively proven and their contribution to urology remains enormous.

Ureteral stents are available in various shapes and made of various materials. Ureteral stents can be divided into polymeric (PSs) and metal mesh stents (MSs). PSs are usually composed of polyurethane and silicon-based polymeric biomaterial. A unique category of PSs is the biodegradable stents which are composed of biomaterials such as poly-L-lactide-co-glycolide (PLGA) or L-lactide-glycolic acid copolymer. MSs are based on metal alloys such as MP35N, nickel–cobalt or stainless steel. Stent designs depend on their use and composition. The most commonly used PS design is the double-pigtail (double-J) design, which is characterized by coil-shaped stent ends. MSs are either MSs identical to those used in coronary vessels or double-J stents composed of metal wire (Resonance) [1].

Regardless of the stent design and composition, the use of ureteral stents is associated with several complications, which limit their use and necessitates the escalation of research towards the introduction of the "ideal" ureteral stent. The properties of the ideal stent include the ability to hold its position (memory) over time (durometry), easy manipulation of its shape (elasticity), and excellent tensile strength while having elongation capacity. Moreover, placement of the ideal ureteral stent should not be associated with degradation of its structure and function (biodurability) or influence the urothelium (biocompatibility). The ideal stent should be radio-opaque and therefore visualized by fluoroscopy [1, 2]. Patient comfort and resistance to bacterial colonization could also be considered important properties of the ideal stent. The ideal stent is currently not available and the problems related to ureteral stenting remain an issue, especially in cases requiring long-term stenting to maintain ureteral patency.

Indications for ureteral stents

The insertion of stents in the ureter serves several purposes: relief of ureteral obstruction, promotion of ureteral healing, and prevention of possible complications. Postoperative nephrostomies are usually avoided by the use of ureteral stents. The stent acts as a scaffold for the growth of epithelium, promotes ureteral healing by aligning the ureteric wall and reduces extravasation around the ureter (less inflammation) [3, 4].

The use of ureteral stents for the management of stone disease provides obstruction/hydronephrosis relief, and reduction of colic and infection incidents. Double-pigtail PSs are inserted in lithiasis patients for temporary management of stone-related obstruction [5]. An absolute indication for the management of stone cases by ureteral stenting is the concomitant presence of ureterolithiasis and active infection [6]. The routine use of double-pigtail PSs after shock-wave lithotripsy (SWL) and ureteroscopy (URS) remains questionable

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[7, 8]. Transplantation-related ureteral strictures are an indication for PS insertion [9–11]. Partial ureteral lacerations are successfully managed by double-pigtail stent placement [12] as are ureteropelvic junction obstructions (UPJO); it provides relief of flank pain and healing of the repaired site after pyeloplasty and endopyelotomy [5]. PSs are also inserted intraoperatively in reconstruction of the ureter to, as mentioned above, provide alignment of the area of the anastomosis and act as scaffold around the ureter, which may eventually facilitate the healing process. Moreover, the presence of a ureteral stent minimizes urine extravasation and reduces ureteral wall edema [5]. Ureteral stents make a significant contribution to the treatment of ureteral fistulas: 85% of such cases are efficiently healed with the use of a PS [13].

Malignant ureteral obstruction remains a challenging field for PSs. Despite the use of PSs as an alternative to nephrostomy tubes in the above cases, extrinsic malignant ureteral obstruction managed by PSs is associated with high failure rates [14, 15]. Two ipsilateral pigtail ureteral stents were proposed as a method to address cases of single stent failure, with various success rates. A new double-lumen double-pigtail stent has also been introduced and evaluated in a pig model, with promising results [6, 16].

MSs have been used for the management of extrinsic malignant ureteral obstruction in cases where PSs have failed. The reported success rates were high and the method proved to be useful [2]. The use of MSs has been expanded in benign cases of ureteroileal anastomotic strictures and UPJO, with promising success rates. In fact, long follow-up of the former indicates that MSs are an alternative to challenging reintervention procedures performed for ureteroileal anastomotic strictures and UPJO [2, 16–18].

Complications of ureteral stents

Long-term urinary drainage by ureteral stent insertion is limited by several complications. These complications are related to the design and material of the stent. Major problems of stent use include infection, patient discomfort, encrustation, migration, and hyperplastic reaction.

Stent syndrome

The "stent syndrome" represents the most common double-pigtail PS-related complication and is characterized by irritative voiding symptoms, flank pain, suprapubic discomfort, and occasional hematuria [5, 6]. Urinary system symptoms may be present in up to 80% of patients with stented ureters. Bladder pain (80%) and incontinence (60%) are important problems for these patients [19]. Insertion technique and stent characteristics are unrelated to these symptoms, while selection of the appropriate stent length is related to reduced morbidity [5, 20, 21]. Voiding symptoms, such as urgency and dysuria, attributed to irritation of the bladder floor by the stent, were significantly more frequent in patients with longer stents [5]. Nevertheless, flank pain was not reduced by the stent length as this symptom is related to vesicoureteric reflux [22]. Softer or tapered lumenless tails have been also proposed for symptoms reduction [23, 24].

Stent migration

Migration of the PSs is associated with stent design. Double-pigtail stents are less prone to migration in comparison to single-pigtail stents. PSs usually migrate towards the kidney rather than towards the bladder. The insertion of the stent under direct cystoscopic vision is advised and the formation of a full loop in the bladder should be confirmed. Migrated stents require URS management for their removal [25]. Challenging cases of ureteral stent extraction require ureteral orifice incision and the use of devices such as embolectomy catheters, and ureteral balloons and baskets [26]. Covered MSs have been associated with rates of migration up to 81.2% [27].

Encrustation

Encrustation is a major problem encountered in long-term ureteral stenting with both PSs and MSs. The risk of encrustation is associated with both the stent biomaterial and the patient's history. Encrustation is always related to biofilm formation despite the absence of evident urinary infection. Biofilm is formed by adhesion of micro-organisms on the stent surface and gradual development of a thin film of extracellular matrix around them [28]. Biofilms and urease-producing organisms on a stent surface induce elevation of urinary pH and precipitation of salts such as calcium hydroxyapatite and magnesium ammonium phosphate. The latter process eventually results in struvite and calcium phosphate accumulation [29]. The subsequent encrustation and infection of stents may be responsible for pain, hematuria, and sepsis [30]. The phenomenon of encrustation makes routine exchange of PSs necessary for the prevention of related complications. "Stone formers" are difficult to manage because the exchange intervals are unpredictable [5].

Encrustation of MSs is associated with the aperistaltic segment of the stented ureter in conjunction with ureteral peristalsis and urinary stasis, resulting in encrustation of the areas of the MS uncovered by urothelium [31]. An encrustation-resistant MS needs to be made of a biomaterial resistant to bacterial infection and subsequent biofilm formation. In addition, it should be easily covered by endothelial cells and become incorporated into the ureteral wall [32, 33].

Urothelial hyperplasia

Urothelial hyperplasia is a significant complication of MS insertion in the ureter. Ureteral patency can be compromised by the development of hyperplastic tissue protruding through the stent struts. The hyperplastic tissue is responsible for restenosis of the stented ureter. An experimental study in a porcine model by Desgrandchamps *et al*. revealed that only one of eight stents was patent 35 days after insertion [34]. It appears that hyperplasia can be prevented by avoiding overextension of the strictured area of the ureter, followed by careful stent implantation. It should be noted that urothelial hyperplasia regresses within 4–6 weeks after MS insertion, resulting in ureteral lumen narrowing [35–39]. Flueckiger *et al*. suggested that the initial effect (first 1–2 weeks) of the inserted MS in the ureter is reactive swelling of the ureter and not hyperplasia of the urothelium leading to constriction of the ureteral lumen [40]. A characteristic trumpet-like morphologic configuration of the ureter located on the upper extremity of the stent has been described, but is not related to ureteral patency risk [27, 39].

Polymeric stents

PSs are the most commonly used ureteral stents and their contribution to urologic practice is invaluable.

A variety of synthetic polymeric compounds has been used for the manufacture of PSs. These materials are based on polyurethane or silicone, such as Silitek (Surgitek, USA), C-Flex (Cook Urological, Spencer, IN, USA), Percuflex (Boston Scientific, Natick, MA, USA) [41, 42]. Silitek is a block copolymer based on silicon, while C-Flex is a proprietary silicone with styrene/ethylene/butylene block copolymer. Percuflex is composed of an olephinic block copolymer. In contrast, Tecoflex (Thermedics, Woburn, MA, USA) is a proprietary aliphatic thermoplastic and is not based on silicone or polyurethane. Polyurethane is a relatively cheap material and has the advantage of high versatility, but its biocompatibility is considered poor and it is related to significantly more urothelial ulceration and erosion [43]. The gold standard of biocompatibility is silicone [44]. Although all the polymeric materials described above are susceptible to encrustation, Siliteck, C-Flex, and Tecoflex are less frequently affected by this complication. Moreover, polyurethane, Silitek, and Percuflex provide high tensile strength [42].

Double-pigtail polymeric stents

The efficiency of retrograde ureteral stenting in obstruction of extrinsic and intrinsic etiology has been reported by Yossepowitch *et al.* [45]. Extrinsic obstruction was associated with a higher degree of hydronephrosis and the site of obstruction was located more distally. Ureteral stents achieved successful alleviation of the obstruction in 94% and 73% of patients with intrinsic and extrinsic obstruction, respectively. Intrinsic obstruction cases were successfully managed at 3 months follow-up, while extrinsic ureteral obstruction was successfully relieved in only 54.6% of the stents after the same time period. Other investigators reported a success rate for retrograde stenting of intrinsic ureteral obstruction of 88%. The mean follow-up was 25.5 months [46]. The experience gained by the same investigators with the management of extrinsic ureteral obstruction by retrograde stenting revealed success rates of 81%, 85%, and 100% for malignant, retroperitoneal fibrotic, and benign etiology obstruction, respectively. Average follow-up was 16 months (range 0.7–98 months) [47].

A large experience with 2431 patients (2685 ureters) who were treated by double-pigtail stent insertion has been recently published [48]. The majority of the indications for ureteral stent insertion were URS or percutaneous lithotripsy, SWL, and open lithotomy. Iatrogenic ureteral injury, extrinsic ureteral obstruction, UPJO, and ureterocysteoneostomy were also managed by double-pigtail stent insertion. Several complications were observed: pain, gross hematuria, bladder irritation, high fever, encrustation, stent migration, and stenosis (or recurrence of stenosis). The mean follow-up period was 31 ± 1.9 days (range 1–123 days). As a result, the insertion of double-J stents for endoscopic and open procedures for upper urinary tract diseases can be considered as a safe and efficient method, at least for up to 4 months.

The long-term outcome of double-pigtail ureteral stenting for the management of extrinsic ureteral obstruction was evaluated by Rosevear *et al*. in a study including experience accumulated over 9 years [47]. In total, 54 patients (87 ureters) with malignant, retroperitoneal fibrosis, or benign tumors were successfully treated in 81%, 85%, and 100% of cases, respectively. The mean follow-up period was 16 months (range 0.7–27 months) and mean interval between stent exchanges was 3.6 months. The average interval to stent failure was 4.8 months (range 0.7–27 months).

Quality of life is an important issue for patients with ureteral stents as the stent-related complications may have a significant impact. Joshi *et al.* investigated the effect of ureteral stents on quality of life and associated urinary symptoms. Storage symptoms, bladder pain, and hematuria were the most common symptoms observed, and at least one symptom was encountered in 80% of the patients. In addition, the available questionnaires did not elucidate the entire range of symptomatology [19].

A coil-reinforced polymeric double-pigtail stent has been recently introduced for the treatment of malignant ureteral obstruction. The Silhouette stent (Applied Medical, Rancho Santa Margarita, CA, USA) has been introduced due to the high failure rate of common polymeric ureteral stents [6]. The stent proved to be more resistant to extrinsic compression in comparison to the also newly introduced double-J all metal Resonance (Cook Urological) [49].

A unique double-pigtail stent is the Zebra (Neo Medical, Germany). It is a Teflon-coated lumenless double-pigtail stent, which facilitates passage of residual stone fragments through the ureter. The comparison of Zebra to standard PSs in two stone-forming patients who underwent SWL revealed no ureteral damage, and after 4 and 5 weeks there was no encrustation on the Zebra stent, while the standard PSs were covered by considerable encrustation [50]. Moreover, the material fatigue evaluation of the Zebra stent in an experimental model simulating the movement of the ureter estimated that the stent would not break even if were left indwelling for 9 months [51].

Ipsilateral and dual-lumen double-pigtail polymeric stents

The use of two ipsilateral double-pigtail polymeric stents for the management of extrinsic ureteral obstruction resistant to a single stent insertion was proposed almost a decade ago [52]. The first report included five patients who were treated for ureteral obstruction due to ureteral orifice stricture, retroperitoneal fibrosis, and middle ureter stricture. These patients were managed successfully by the insertion of two ipsilateral 7F ureteral stents, which were exchanged at 3-month intervals until the patients were managed surgically [52]. In a subsequent report, malignant ureteral obstruction in seven patients was managed by the insertion of two ipsilateral stents [53]. Previous insertion of a single double-pigtail stent had been unsuccessful in the management of the obstruction. Three patients died within 3 months after the insertion of the two ipsilateral stents, while the remaining four had a mean follow-up of 16 months (38 months maximum). Stents were exchanged every 4–6 months to avoid long-term complications.

A novel dual-lumen double-pigtail stent composed of two adhered ureteral stents has been evaluated in a porcine model. The stent provides better flow in comparison to a single ureteral stent. The main advantage of this stent is that its insertion requires only one guidewire, whereas insertion of two ipsilateral stents requires two guidewires, making the procedure more cumbersome [16].

Biodegradable polymeric stents

Biodegradable polymeric materials and stents have been proposed in urology for over a decade. Their main advantage is that they do not need to be removed. An additional procedure for the extraction of the inserted stent is not necessary, the complications of this procedure are avoided, and the period of discomfort for the patient is shortened [6, 42].

In a porcine model, a PLGA ureteral stent inserted after experimental Acucise™ balloon incision endopyelotomy was shown to provide similar drainage to a standard PS (Applied Medical) in pigs, but its biocompatibility was not favorable compared to a standard stent since the musculature of the incised ureteral segments revealed inferior healing [54].

A biosolvable ureteral stent (TUDS; Boston Scientific) was evaluated in terms of biodegradation and biocompatibility in a porcine model. The stent is designed to maintain ureteral patency for 48 h, after which it softens and eventually degrades. Histologic results were similar for both a standard hydrogel-coated stent and TUDS [55]. The clinical assessment of the TUDS stent showed safe and efficient drainage. Dissolution took place in 90% of the stents after an average of 8 days. Satisfaction was reported by 89% of the patients treated by TUDS [56].

Tajla *et al*. evaluated a horn-shaped helical PGLA stent that was used for the postoperative management of antegrade endopyelotomy (cold-knife technique) performed for UPJO [57]. *In vitro* studies estimated the degradation time for the stent to be 2–2.5 months. Percutaneous nephrostomy or stent removal procedures were not deemed necessary for the treated patient. The stent contributed to the reduction of vesicoureteral reflux and postoperative renal infection due to its function as a partial catheter.

Drug-eluting and drug-coated polymeric stents

Recently, polymeric ureteral stents that are coated with pharmaceutical substances or release drugs from their surface to the surrounding tissue have been introduced and clinically tested. Triclosan is a broad-spectrum antibacterial and antifungal agent which has been reported to inhibit the growth of common bacterial uropathogens *in vitro*, and is thus considered useful for the reduction of urinary tract infection and subsequent encrustation of an indwelling stent [58]. A significant decrease in *Proteus mirabilis* growth and survival was observed in a rabbit experimental model when a triclosan-eluting ureteral stent was inserted in the urinary system (bladder)

[59]. In eight patients significantly fewer antibiotics were administered, and there was a slightly higher number of positive urine cultures, but significantly fewer symptomatic infections with long-term use of the triclosan-eluting stent. Bacterial resistance to triclosan was not noted during the 3-month follow-up period [60].

A recently introduced ketorolac-eluting stent was evaluated for its short-term efficacy in a double-blind randomized multi-institutional clinical trial [61]. The 276 patients included were divided into two groups (triclosan stent and conventional stent). There were no significant differences in primary and secondary intervention rates between the two groups. Fewer patients with the ketorolac-eluting stents used pain medication in comparison to the control group.

A heparin-coated double-pigtail ureteral stent was introduced in an attempt to minimize microbial adhesion, biofilm formation, and subsequent encrustation of long-term indwelling stents in the urinary tract. In five patients, a heparin-coated ureteral stent was inserted in one ureter and a conventional double-pigtail stent in the other for a month [62]. The thickness of the encrustations observed by electron microscopy on the heparin-coated stents was significantly less in comparison to that on the conventional ureteral stents. Moreover, the encrustation on the heparin-coated stents was less uniform and more compact. Two heparin-coated stents were left indwelling long term (10 and 12 months) and on removal showed no evidence of encrustation and an unchanged heparin layer.

Metal mesh stents

Self- and balloon-expandable metal mesh stents

MSs used in the ureter can be divided into four general groups: self-expandable, balloon-expandable, covered, and thermo-expandable shape-memory stents. Covered MSs were introduced in an attempt to minimize tissue ingrowth, which eventually compromises ureteral patency [27]. MSs implanted in the ureter for the management of various malignant and benign diseases are the Wallstent (Microvasive, Natick, MA, USA), Memokath 051 (Engineers & Doctors A/S, Kvistgaard, Denmark), self-expanding polytetrafluoroethylene-covered nitinol stent (Hemobahn Endoprosthesis, W.L. Gore and Associates, Flagstaff, AZ, USA), and the recently introduced all-metal double-pigtail Resonance stent (Cook Urological).

The Wallstent is composed of braided biomedical cobalt-based alloy monofilaments and is the most extensively used self-expandable endoprosthesis in the ureter [1]. Inserted in the ureter it appears to represent a safe and effective method for the palliative treatment of malignant ureteral strictures. Benign and malignant ureteral strictures in patients not suitable for surgical treatment were treated with the Wallstent by Pollak *et al*. [63] One of six stented ureters were patent after 11 months. In two patients, three stents were implanted for the palliative management of malignant disease and were patent up until death (3–5 months after implantation). Ingrowth of hyperplastic and granulation tissue was responsible for the occlusion of all stents inserted for benign strictures, while tumor ingrowth and granulation tissue were observed in malignant cases. Wallstent endoprosthesis proved to be ineffective for long-term drainage in patients with benign ureteroenteric strictures . The mid-term clinical outcome of the Wallstent self-expandable stent implantation for the management of malignant ureteral obstruction was evaluated in 40 patients with 54 malignant ureteral obstructions [37]. Patency was confirmed in 51 of the stented ureters during the mean follow-up period of 10.5 months (range 1–44 months). Almost half of the ureters (49%) required additional procedures to maintain patency. Adequate drainage preventing hydronephrosis was observed in the majority of the cases and major complications were not encountered.

Malignant ureteral strictures due to gynecologic cancer were managed in 14 patients with self-expandable MSs in a report by Barbalias *et al*., and ureteral obstruction was relieved in all cases [64]. The mean follow-up time was 15 months (range 9–24 months). Tumor ingrowth requiring additional coaxial stent placement and borderline tumor overgrowth were observed in one case each. Urothelial hyperplasia was noted in all stented ureters and additional retrograde insertion of a double-pigtail stent was deemed necessary for a 1-month period. On the proximal edge of the stent, a mild ureteral narrowing was noted (trumpet-like configuration), which did not impact ureteral patency. The trumpet-like configuration was a constant finding during the follow-up period. The authors concluded that the implantation of self-expandable MSs is a safe and effective method for by-passing gynecologic malignant ureteral obstruction.

The combination of self-expandable MSs with coaxial double-pigtail stents was proposed by Hekimoglou *et al.* [31]. Ten ureters (10 patients) with malignant obstruction were treated with this combination. The double-pigtail stents were removed in seven patients 2 and 3 months after the implantation. Six patients developed hydronephrosis and double-pigtail stents were reinserted. PS exchange was performed at 3-month intervals. The MS lumen was compromised by hyperplastic tissue and encrustation. Nevertheless, this combination was adequate to achieved internal urinary drainage.

Several authors have reported promising results with the management of ureteroileal anastomotic strictures by MS insertion [17, 65–72]. In these reports between 1 and 18 patients were treated, while the number of treated ureteroileal strictures ranged between 1 and 24. The mean follow-up period ranged from 6 to 22 months. Stricture recurrence was observed by the majority of the authors. Our group reported long-term results in 18 patients with ureteroileal anastomotic strictures who were managed with MS placement [17]. Mean follow-up was 21 months (range 7–50 months). The technical success rate of stricture crossing and stenting was 100%. Immediate poststenting patency rate was 70.8% (17 of 24 cases), while primary patency rates at 1 and 4 years were 37.8% and 22.7%, respectively. Fifteen stented ureters required secondary interventions. Secondary patency rates were 64.8% and 56.7% at 1 and 4 years, respectively. Periodic exchange of external–internal double-pigtail catheters until the end of the follow-up period was performed in six ureteroileal conduits. Definitive treatment for the ureteroileal strictures was achieved by MSs in more than half of the cases. The remaining cases were managed by regular exchange of double-J catheters in retrograde fashion. Surgical revisions of ureteroileal anastomotic strictures are challenging, while MS implantation provides efficient drainage while preserving the quality of life.

Barbalias *et al*. have proposed the use of self-expandable MSs for the management of UPJO [18]. MSs were placed in four patients who had previously undergone open pyeloplasty and in whom recurrence of UPJO was diagnosed. The mean follow-up period was 16 months (range 9–24 months). The placement procedure was successful in all cases and patency was confirmed in all four patients. Ingrowth of fibrotic tissue through the stent led to additional coaxial overlapping MS insertion in one patient 2 months after initial stent placement. The results were promising and the authors suggested the performance of more extensive clinical trials in order to validate this application of MSs.

Balloon-expandable stents have not been extensively used in the ureter. Barbalias *et al*. treated six patients with malignant disease with self-expanding stents and six with balloon-expandable stents [36]. Additional interventions were deemed necessary in three cases due to urothelial hyperplasia, tumor ingrowth, and local recurrence of primary cancer invading the upper end of the ureter. Mean follow-up was 9 months (range 8–16 months).

Memokath 051 represents a unique type of MS. It is a thermoexpandable shape-memory stent composed of nickel and titanium alloy. It has a tight spiral structure, which prevents urothelial growth [73]. The Memokath 051 softens below 10 °C and regains its shape when reheated to 50 °C. The thermal shape memory feature makes the removal of the stent possible. Kulkarni and Bellamy have used the endoprosthesis for the management of ureteral obstruction of both benign and malignant etiology [74]. Long-term results for the management of malignant and recurrent benign strictures are available: 18 malignant and 10 recurrent benign cases were treated with the Memokath 051 and followed up for a mean of 19.3 months (range 3–35 months). At the end of the follow-up period, 15 stents (13 patients) provided adequate drainage, while eight patients carrying 13 functioning stents had died. Infection and migration were not observed. In general, the Memokath 051 proved to be advantageous over conventional double-J catheters. Moreover, the potential for removal of the stent due its thermal memory was a significant advantage over conventional MSs. This removal capability was not a feature of any other MS until the introduction of the Resonance double-pigtail MS.

Such favorable results with the Memokath 051 were not reported by Klarskov *et al*., who used it to treat 37 stenosed ureters (33 patients) attributed to both malignant and benign conditions [75]. The mean follow-up period was 14 months (range 3–30 months). Migration towards the bladder was observed in 10 stents and 12 stents malfunctioned, giving a total of 22 nonfunctioning MSs. Encrustation resulted in occlusion of four stents at intervals after stent insertion ranging between 1 and 10 months.

Li *et al*. evaluated a titanium–nickel alloy-based self-expandable stent in benign ureteral strictures over a long mean follow-up period of 92 months (range 12–131 months) [76]. Encountered complications included hyperplastic reaction, infection, and encrustation with stone formation. The investigators concluded that MSs could adequately manage selected cases of ureteral strictures.

Recently, we reported our 10-year experience with metal mesh stenting for the management of malignant ureteral obstruction [77]. Ninety patients (119 ureters) with ureteral obstruction from various pelvic and metastatic tumors were treated with several different types and brands of MSs in an attempt to provide long-term urinary drainage without requiring nephrostomy tubes, and followed up for a mean of 15 months (8–38 months). Hyperplastic reaction and/or tumor ingrowth resulting in tissue protruding through the stent struts and obstructing the stent lumen was the most common problem and was addressed by repeat balloon dilations. Those cases resistant to balloon dilation were managed by insertion of a double-pigtail stent coaxially, which assured ureteral patency. With primary and secondary patency rates of 51.2% and 62.1%, it was concluded that metal mesh stenting of the ureter should be carefully considered for long-term urinary drainage.

Covered metal mesh stents

Covered MSs were introduced as a solution to the urothelial hyperplasia compromising the patency of conventional MSs. The high migration rate (81.2%) of covered MSs, which could induce renal colic, represented a major problem in clinical application and minimized further use of these stents in the urinary tract. The inability of covered MSs to anchor into the ureteral wall was associated with the coating material and the enhanced ureteral peristalsis [27]. Migration was managed by cystoscopic removal of the migrated covered stents and the coaxial insertion of bare stents.

Recently, an S-shaped covered MS was introduced and underwent comparative evaluation to bare MSs in the canine ureter. The shape of the stent was responsible for the anchoring into the ureteral wall. The stent was covered with polytetrafluoroethylene (PTFE) for prevention of lumen occlusion due to hyperplastic reaction. Both migration and the hyperplastic ureteral obstruction were avoided [78]. Clinical investigation with this stent will help to clarify the controversial results with covered MSs.

Double-pigtail metal stents (Resonance)

The Resonance stent (Cook Urological) was recently introduced as an all-metal double-pigtail stent. It is composed of MP35N alloy (nonmagnetic nickel–cobalt–chromium–molybdenum alloy) in a tight spiral structure. Ureteral obstruction, due to either malignant or benign conditions, can be managed with Resonance [79–82]. Borin *et al*. were the first to report a case of Resonance stent insertion and successful management of ureteral obstruction due to retroperitoneal fibrosis from metastatic breast cancer [79]. The obstruction had not been controlled by the previous insertion of two 6F double-pigtail PSs. The ureter was patent over a 4-month follow-up period. Resonance stent insertion was used to manage malignant ureteral obstruction without bulky pelvic disease in 15 patients (17 ureters) who were followed up for between 1 week and 8 months [80]. In three patients, the initial stent was exchanged after 6 months and after 12 months in one patient. Long-term drainage of the obstructed ureters was reported to be efficient and encrustation was minimal. Stents were patent and functioning in four patients who were still alive at the end of the follow-up period. The Resonance stents were not removed in seven patients who died during the follow-up period. Nagele *et al*. treated 14 patients (18 ureters) with ureteral obstruction of either benign (n = 5) or malignant etiology(n = 13) [81]. Mean follow-up was 8.6 months. Encrustation was evident on two stents. Seven stents were removed due to persistent hematuria, severe dysuria, pain, and inadequate drainage. In an attempt to ensure patient comfort, an appropriate stent length should be selected. In addition, satisfactory drainage under circumstances of extrinsic ureteral obstruction was confirmed by an experimental study. Nevertheless, less overall flow than with a standard PS was noted for the Resonance stent [83].

Our group assessed in a porcine model the effect of SWL or radiotherapy on ureters with an indwelling Resonance stent. The histologic deterioration of pig ureters stented with Resonance was not significant compared to control ureters (standard stents) after SWL or radiotherapy, and ureteral temperature was not detected to be significantly higher for the Resonance ureters [84, 85].

The clinical efficiency of Resonance was evaluated by our group in a clinical trial including 50 patients with malignant or benign ureteral obstructions [82]. All cases of extrinsic obstruction due to malignant factors were managed adequately (25 patients), while patency was observed in 44% of the benign intrinsic obstruction cases (25 patients). The benign case group included patients with lithiasis, ureteroileal obstruction, iatrogenic strictures, or an occluded ureteral MSs and who were contraindicated for any surgical or endoscopic procedures due to comorbidities. Further clinical trials are deemed necessary to clarify the indications for the insertion of the Resonance stent. Average overall follow-up was 8.5 months (range 4–14 months), and the mean follow-up for malignant and benign cases was 11 months and 6.8 months, respectively. The removed Resonance stents underwent laboratory investigation to identify the presence of encrustation and the type of deposits. Encrustation was evident in 20% of the extracted stents. The most common location of enscrustation was the edges of the stent. Even stents without evident encrustation were observed to have deposits on scanning electron microscopy (Figures 67.1). Calcium oxalate was the most frequent encrustation deposit.

The clinical application of the Resonance stent in ureteroenteric strictures was reported to be unsuccessful by Garg *et al*., who inserted it for the management of 10 strictures in 10 patients with ileal conduits [86]. Distant migration was observed in nine cases in a mean of 21 days (range 3–60 days). More recently, Lopez-Huertas *et al*. managed 13 patients with benign upper urinary tract ureteral obstructions with the Resonance stent (15 stents) [87]. The majority of the stents provided adequate drainage and 12 patients were efficiently managed. The stents were removed in three patients who showed voiding symptoms such as hematuria. The remaining patients had their stents exchanged after a mean follow-up of 11.6 months. The investigators also conducted a cost-effectiveness analysis and reported a significant cost reduction in favor of the Resonance stent.

Drug-eluting metal mesh stents

Interventional cardiology has gained significant experience with drug-eluting MSs (DESs). In fact, the DESs

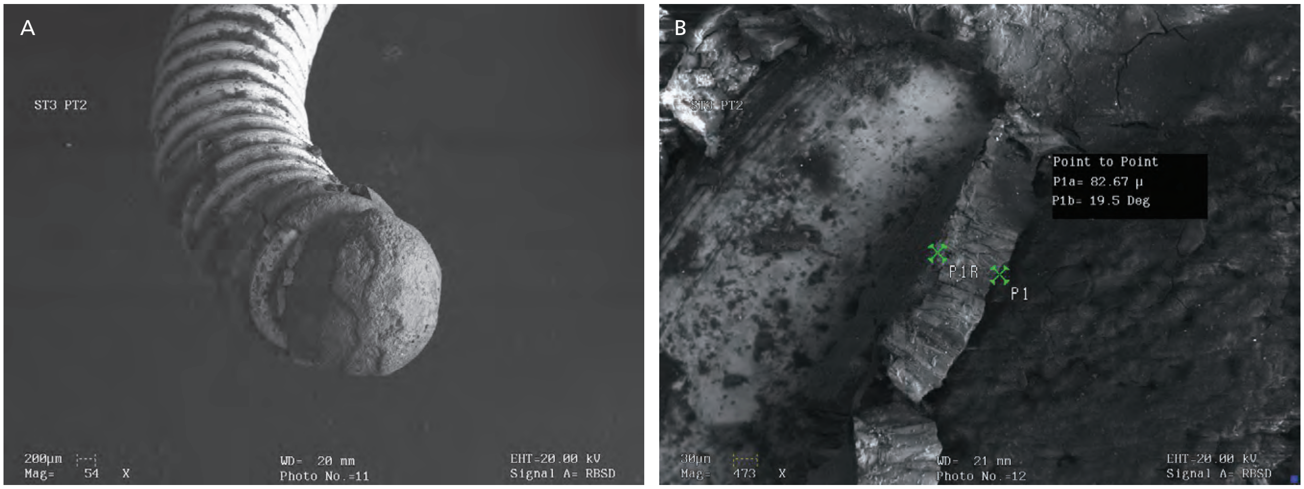

Figure 67.1 (A) Scanning electron microscopy image obtained from the lower extremity of a Resonance stent that was indwelling for 9 months. Note the encrustation layer, which was barely visible macroscopically. (B) Same Resonance stent at higher magnification. The crystals of the encrustation deposits are visible.

represent the most commonly used stents in this specialty. The concept of DESs is to minimize or even eliminate the reaction of the coronary tissue to the stent, which is responsible for platelet adhesion (activation of coagulation cascade) and neointimal hyperplasia [88]. The use of DESs in the ureter is currently limited to experimental animal studies, which have demonstrated reduction of ureteral tissue hyperplasia. Our group has investigated the effect of the paclitaxel-eluting stent in porcine ureters (10 pigs in total). A DES was inserted in one ureter and a bare MS in the other ureter of each animal. Over a follow-up period of 21 days, the majority of MSs were occluded and the remaining MSs were stenosed by hyperplastic reaction, while all the DESs were patent [89]. Recently, we evaluated zotarolimus-eluting MSs (Endeavor; Medtronics, Minneapolis, MN, USA) in porcine and rabbit models. Three weeks after placement we observed less hyperplastic reaction in the DESs in comparison to the bare MSs, which were used as the control in the contralateral ureter of the same animals (unpublished data) (Figure 67.2). The effectiveness of DESs in these animal models is promising for their clinical application.

Outcome of long-term ureteral stenting

The long-term use of ureteral stents currently represents a challenge for biomaterial science, pharmacology, and urologic research [1]. The frequent exchange of double-pigtail PSs is accepted clinical practice, with complications addressed by pharmaceutical therapy or additional interventions, and these stents should not be expected to be in place for longer than a few months. While cases

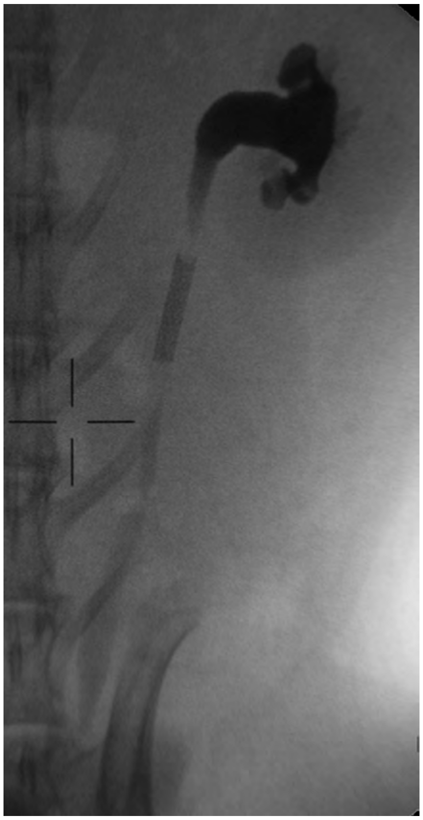

Figure 67.2 Fluoroscopic image of a zotarolimus metal stent a week after its insertion in a rabbit ureter. Note the trumpet-like configuration on the ureter segment located at the upper extremity of the stent. The configuration did not influence the patency of the stent. Note the lack of hyperplastic reaction in the lumen of the stent.

of ureteral PSs indwelling for longer periods (even years) have been reported, and several methods proposed for their extraction, they are challenging cases and represent a "headache" for the urologist [90]. Clinical experience with biodegradable PSs remains limited and further refinement is necessary for the wide acceptance of these stents [1]. The development of newer biodegradable materials could lead to the introduction of new biodegradable stents. Drug-eluting and drug-coated PSs are rapidly evolving and their first clinical application appears promising. Moreover, the potential of the latter stent type could be increased with the countless pharmaceutical substances that could be used on their surfaces.

MSs are a completely different category of stent and are used significantly less frequently in urologic practice. Nevertheless, experience has accumulated over the years. Long-term results have proved to be poor despite the initial promising outcome [1, 77]. Thus, patients should be carefully selected for stenting with an MS. The first MS with a double-pigtail design provides adequate drainage in cases of PS failure and has shown excellent results in long-term management of malignant ureteral obstruction. In contrast, benign cases have been associated with unfavorable results. Further clinical investigations will elucidate the true efficacy and indications for these stent [82]. DESs are the next step in the evolution of metal stenting in the ureter. These stents have a tremendous impact in interventional cardiology. Their use to overcome the difficulties encountered during metal stenting is expected. Available experimental reports are rare but still promising regarding the possible outcome in clinical trials.

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- 97 videos showing procedures described in the book
- A search feature
- All videos referenced in the text where you see this logo 👁

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Foreword

"End of Urology," so spoke the late Richard Williams, my good friend and colleague, when as residents we witnessed a newly arrived faculty* at the University of Minnesota begin to do with tubes and wires through small holes what we could do so much more adeptly and expeditiously through our macho incisions. "A flash in the pan," so commented the renowned Victor Politano at a meeting in the mid 1980s where Endourology was being presented. "Small incisions are for small surgeons," – the words of surgeon advocates of the massive incision because exposure was king and, after all, incisions healed from "side to side."

"Endourology" was the branding brainchild of Elwin Fraley, Arthur Smith, and Paul Lange. Most felt that the Minnesota cold had finally gone beyond their defenses to create a "brain freeze" of monumental proportions. Fast forward 30 years and, today, Endourology has become Urology. From the urethral meatus to the uppermost renal calyx, the entire urogenital tract is endoscopically accessible and radiologically visualizable. From the smallest to the most complicated open procedure, urologists of talent, innovation, and persistence have supplanted standard incisional access with the endoscope or image-guided therapy. This is the age of surgical nihilism and Endourology has been at the forefront from day one.

If you are reading this foreword, then you hold in your hands a book (or CD) that contains every aspect of Urology and how it is impacted by a minimally invasive approach, be it percutaneous, ureteroscopic, laparoscopic, robotic, or image-guided. The authors are a Who's Who of experts in endourology on a global scale. The content ranges from basic to futuristic Endourology. The latest advances in supine percutaneous stone removal, endoscopic nephrostomy, laparoendoscopic single site surgery as well as natural orifice transluminal endoscopic surgery are clearly detailed and illustrated both in still photographs and often by instructional video demonstrations.

A wise mentor* once informed me that "You are only as good as tomorrow." That single daunting sentence should haunt each of us as we arise every morning to provide relief to those who suffer. To that end, we must seek methods to relieve suffering without causing it, to heal without harming, to cure without creating another, sometimes worse, malady. Endourology empowers every urologic surgeon with the knowledge and tools to provide all individuals seeking our care with a kinder gentler solution to their problem…one that neither disfigures nor maims in the name of treatment. In the words of Sir William Osler "Diseases that harm, require treatments that harm less." A century later, his dictum has become commonplace practice for the endourologist.

My heartfelt congratulations go out to Drs Smith, Badlani, Kavoussi, and Preminger – friends all – to me, to you, and to your patients. So read *Smith's Textbook of Endourology* well, apply its principles earnestly, and if opportunity presents, seek to innovate and improve. The text is not an end in and of itself, rather it is another paver in the surgical journey in which each of us plays a role – using techniques born of today's technology to ever reduce the burden of the "surgical" cure.

Ralph V. Clayman

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*(Arthur D. Smith)

Preface

In 1978 the concept of Endourology was launched. It was defined as closed controlled manipulation within the urinary tract. The word "closed" was used to indicate either a minimal incision or no incision at all and the "control" was achieved either endoscopically or by non-invasive imaging. Until then, residents had been taught that the only way to get good exposure was through a large incision and now the ultimate goal is good exposure with no incision at all. It is achieved with a combination of endoscopy and all the new modalities of imaging. Now there are relatively few accepted open urological surgical procedures and this has had the gratifying result of a dramatic decrease of the morbidity in our patients recuperating after treatment. Because the field has expanded exponentially over the past three decades, the need has arisen for a new updated edition of this textbook.

From the outset, it has been policy of Endourologists to embrace, and evaluate fairly, all new tools and equipment. Consequently we have always been at the cutting edge of new technology. As technology has evolved, courses have been organized, to train not only residents and fellows, but also the practicing urologist, so that their learning curve has been accelerated enabling them to practice endourologic techniques comfortably and with the required expertise. The number of stone cases treated by open surgery today is minimal. Similarly open nephrectomy has almost exclusively been replaced by laparoscopic, robotic or percutaneous ablative techniques.

In this era of fewer working hours for residents, the amount of time that the residents spend in the operating room has decreased dramatically, and the necessary skills have to be taught using a combination of additional educational modalities. In addition to books and journals, there are an abundance of videos on surgical techniques, animal laboratories, teaching models and virtual reality simulators. Fortunately endourologic techniques are uniquely suited to these modalities and the student can become quite adept before being instructed in the operation room. These learning tools have helped urologists all over the world to become competent endourologists.

This 3rd edition has been completely re-written as the field has expanded to incorporate so many applications. The contributors to each chapter are either the innovators of the procedure they describe or alternatively have had vast experience with that technology. Wherever possible we have included videos to enhance the description of the various techniques and the readers will have the opportunity to watch experts doing the procedures. These videos are on portable computer discs which can be seen shortly before any intended endourologic operation as a "re-fresher."

The "Textbook" consists of 2 volumes – the 1st one on stones in the upper tract and the 2nd on laparoscopic and robotic surgery, image guided diagnostics and therapeutics and minimally invasive therapy of the lower urinary tract. The 1st volume has 5 parts:

Section 1 discusses basic principles of the care of instruments, how to protect oneself from radiation exposure, video imaging and documentation which has become so important in the area of electronic medical records. As gram negative septicemia is still prevalent in the management of stone patient's , antibiotic usage in the prevention of sepsis is included in the section. There is a chapter on anti-coagulant therapy which is so prevalent today in patients with coronary artery stents.

Section 2 is devoted to percutaneous renal surgery, from pre-operative evaluation to access, stone removal, other uses of the nephrostomy tract and the exit strategy and complications.

Section 3 discusses all the intricacies of ureteroscopy and Section 4 is devoted to shock-wave lithotripsy. We were cognizant that there is no single modality for treating stones and hence Section 5 describes the management of the patient with various stone related problems in a composite format.

As there is so much overlap between laparoscopic and robotic surgery we combined them in Section 6. At present, the dividing line between the techniques is primarily related to technical experience and availability of the robot together with financial considerations.

Section 7 which discusses image-guided diagnostics and therapeutics, is an important addition to this textbook on Endourology as it is an essential component of the armamentarium of the practicing urologist.

We are moving into an era of "no incisions", and if the procedures described in this section are not performed by urologists, they will be taken over by radiologists. This would result in the loss of continuity of care of our patients.

Finally, Section 8 discusses management of the lower urinary tract. Emphasis has been placed on many ambulatory procedures, as this is an escalating trend endorsed by medical insurance plans.

I would like to thank each of the contributors for the many hours they devoted to writing, illustrating and creating videos for their chapters.

Hopefully they will be as delighted with the results as the editors and publishers of this "Textbook." I am also deeply indebted to my co-editors who have reviewed edited and re-reviewed chapters countless times. I thank not only them but their families as well, for the time spent on the book could have been devoted to them.

The staff at Wiley-Blackwell have been highly efficient, professional and encouraging. When one deals with a large organization it is reassuring to know that as the book passes from one stage to the next and hence to separate departments there is "continuity of care" throughout the operation. They are a great team and we, the editors, appreciate all the help we received from them.

Finally I would like to thank my wife, Kay, who inspired me to edit this 3rd edition and has repeatedly helped me with this text and countless other projects throughout my academic career. If I am regarded as the "father" of Endourology, she is unquestionably the "mother" that helped nurture this field of urology.

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SECTION 6
Laparoscopy and Robotic Surgery

CHAPTER 68

Patient Preparation and Operating Room Set-up for Laparoscopic and Robotic Surgery

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Introduction

Laparoscopic and robot-assisted procedures have become the cornerstone of a urologist's surgical armamentarium over the past two decades. These minimally invasive procedures require additional equipment and operating room set-up. Patient and operating room preparation are key features to successful and efficient surgery.

It is imperative that the operating room personnel and surgeon are familiar with all equipment systems and proper preparation of equipment. Urology surgical team members also need to be able to troubleshoot unexpected occurrences during a case. Without proper preparation and positioning, patient safety and surgical outcomes may be compromised. In this chapter we describe key features of patient preparation and operating room configuration for common laparoscopic and robotic surgeries.

Patient preparation

Careful patient selection for minimally invasive urologic procedures is critical for successful outcomes. Patient selection begins with a thorough history and physical examination, including attention to cardiopulmonary status and previous abdominal surgeries. Medical and/or cardiovascular clearance may be warranted. Patients with chronic obstructive pulmonary disease require pulmonary clearance, including pulmonary function tests, because of the risk of hypercarbia. Appropriate laboratory data, such as complete blood count, basic metabolic panel, prothrombin time, partial thromboplastin times, and urinalysis with culture should be considered. Radiologic imaging is helpful for surgical planning. For example, computed tomography (CT) with intravenous contrast is valuable for delineating the renal vascular supply for laparoscopic nephrectomy or partial nephrectomy, or for identifying crossing vessels prior to pyeloplasty.

The indications for laparoscopic and robotic urologic procedures are almost identical to those of open surgery. Absolute contraindications to minimally invasive surgery include uncorrectable coagulopathy, abdominal wall infection, massive hemoperitoneum, and generalized peritonitis [1]. Intestinal obstruction was formerly considered an absolute contraindication; however, many general surgeons will perform diagnostic laparoscopy for small bowel obstruction if the bowel is not too dilated. Historically, relative contraindications to minimally invasive surgery included morbid obesity, extensive prior abdominal/pelvic surgery, pelvic fibrosis, organomegaly, ascites, pregnancy, hernias, and iliac or aortic aneurysms. However, in this current day and age laparoscopic and robotic surgery can be safely performed in patients with morbid obesity and previous abdominal surgery with minor technical adaptations. For example, trocar placement for laparoscopic renal surgery can be shifted laterally for obese patients and the Veress needle can be introduced off site from abdominal scars in patients with previous abdominal incisions during initial insufflation. Pregnancy is no longer considered a contraindication for laparoscopy.

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Informed consent

All patients should understand the risks, benefits, and alternatives of the proposed procedure. Complications associated with minimally invasive procedures are similar to their open counterparts with the exception of a few unique complications, including CO_2 embolism, hypercarbia, postoperative crepitus, and shoulder pain from pneumoperitoneum. Every patient who undergoes a laparoscopic or robotic procedure should understand the potential for conversion to an open procedure and this should be documented in the written consent.

Consent for blood products

For surgeons who have experience with laparoscopy, blood type and screen can be sufficient for most minimally invasive urologic procedures. Type and cross for 2 units of packed red blood cells is appropriate for more extensive procedures, such as partial nephrectomy and radical cystectomy. We do not recommend preoperative donation of autologous blood prior to robot-assisted radical prostatectomy because of lower estimated blood loss due to pneumoperitoneal compression of venous blood supply with the laparoscopic approach [2].

Bowel preparation

Preference for bowel preparation varies from surgeon to surgeon. It is our recommendation that patients take a half bottle of magnesium citrate for transperitoneal laparoscopic or robotic renal procedures and that radical prostatectomy patients additionally administer a Fleet enema on the morning of surgery. Many minimally invasive urologic surgeons do not routinely administer a bowel preparation prior to laparoscopic or robotic renal or prostate surgery.

Our preference for bowel preparation prior to robot-assisted radical cystectomy is mechanical bowel preparation only with an oral electrolyte solution. We no longer routinely administer antibiotic bowel preparation (i.e. oral neomycin and metronidazole); however, broad-spectrum antibiotics are administered intravenously within 60 min of incision.

Operating room set-up

Operating room set-up, experienced nursing staff, and a team approach are keys to a smooth procedure. All operating room personnel should be familiar with the operating room set-up and basic equipment function. Minimally invasive procedures require more equipment than standard open procedures; thus, the operating room should be large enough to accommodate the laparoscopic tower and the robotic system.

Table 68.1 Basic equipment for laparoscopic surgical procedures.

Mobile video cart with monitor
Secondary video cart
CO_2 insufflator with CO_2 tank or wall supply
CO_2 insufflation tubing
Camera, high-resolution and control box
0° and 30°, 5- or 10-mm laparoscopes
Scope warmer
High-intensity light source
Fiberoptic light cable
Electrosurgical cords
Electrosurgical unit with foot pedal (LigaSure, monopolar, Harmonic scalpel)
Aspiration–irrigation system with double canister suction apparatus
Two S-shaped retractors
Two Allis clamps
DVD recorder (optional)

All equipment should be tested prior to each procedure to make sure it is functional, including the aspiration–irrigation system, electrocautery, CO_2 insufflation, camera, and light source. The argon beam electrocautery or saline-enhanced radiofrequency cautery should also be tested prior to partial nephrectomy. Lists of equipment necessary for laparoscopic and robotic renal surgery, as well as robotic pelvic surgery, are given in Tables 68.1–68.3. An open tray should be either set up or immediately available in the room in the event rapid conversion to open surgery is needed.

The room configuration for renal surgery varies from left to right side and from laparoscopic to robotic cases. Aerial diagrams of room set-up for laparoscopic transperitoneal renal surgery and robotic pelvic surgery are shown in Figures 68.1–68.3.

Most laparoscopic renal surgeries are performed with the surgeon and assistant on the same side of the table. Thus, two video monitors are ideal with the main laparoscopic tower (containing video monitor, light source, camera, and insufflators) placed on the side opposite the surgeons. The CO_2 insufflator is placed within the surgeon's view to allow for continuous monitoring of the intraperitoneal pressure. The second video tower is placed in view of the second assistant and the scrub nurse who are stationed on the side opposite the surgeons along with the instrument table. Incoming lines from the camera, light cord, CO_2 insufflation tubing, aspiration–irrigation tubing, and electrosurgical devices

Table 68.2 Equipment for laparoscopic renal surgery.

One Veress needle	Two 5-mm atraumatic grasping forceps (blunt)
	One 45-mm endovascular stapler
One 5-mm trocar	Two endovascular stapler reloads
Two 12-mm trocars	One laparoscopic monopolar scissors, Harmonic scalpel, LigaSure (Covidien, Boulder, CO, USA)
One aspiration–irrigation tubing and probe	
Additional equipment for laparoscopic partial nephrectomy	
Four bulldog clamps with remover	FloSeal Hemostatic Matrix (Baxter, Deerfield, IL, USA)
One Satinsky clamp	Hem-o-lok ligation system (Teleflex Medical, Research Triangle Park, NC, USA)
Additional 12-mm trocar for assistant	Lapra-Ty absorbable suture clips (Ethicon, Somerville, NJ, USA)
Laparoscopic ultrasound	2-0 polyglactin CT-1 suture
0-vicryl CT-1 x 3	Closed suction drain
Closed suction drain	

Table 68.3 Equipment for robot-assisted laparoscopic radical cystectomy.

One Veress needle	One laparoscopic scissors
Three 8-mm robotic trocars (for daVinci S, Si, or fourth arm)	Hem-o-lok ligation system (Teleflex Medical, Research Triangle Park, NC, USA)
Two 12-mm trocar	One 10-mm titanium clip applier (optional)
One 5-mm trocar	One 2-0 polyglactin CT-1 suture cut to 10 inches for dorsal vein stitch
One aspiration–irrigation tubing and probe	One 3-0 RB-1 cut to 6 inches for posterior reconstruction stitch (optional)
Robotic monopolar scissors	Two 3-0 UR-6 tied together as a “double-armed” stitch, cut to 7 inches each
Robotic bipolar Maryland grasper	One 3-0 RB-1 available for anterior bladder neck reconstruction
Robotic prograsp	One 10-mm Endocatch bag
Robotic fenestrated bipolar electrocautery (optional)	One 18F Foley catheter (intraoperative catheter)
Robotic Harmonic scalpel (optional)	One 20F Foley catheter (final catheter)
One 5-mm atraumatic grasping forceps	Closed suction drain
One laparoscopic needle driver	
Additional equipment	
30° down camera lens	
One 15-mm trocar for assistant	
One 12-mm trocar for assistant	
Laparoscopic LigaSure (Covidien, Boulder, CO, USA)	
Laparoscopic endovascular stapler (optional)	
Open tray for urinary diversion	

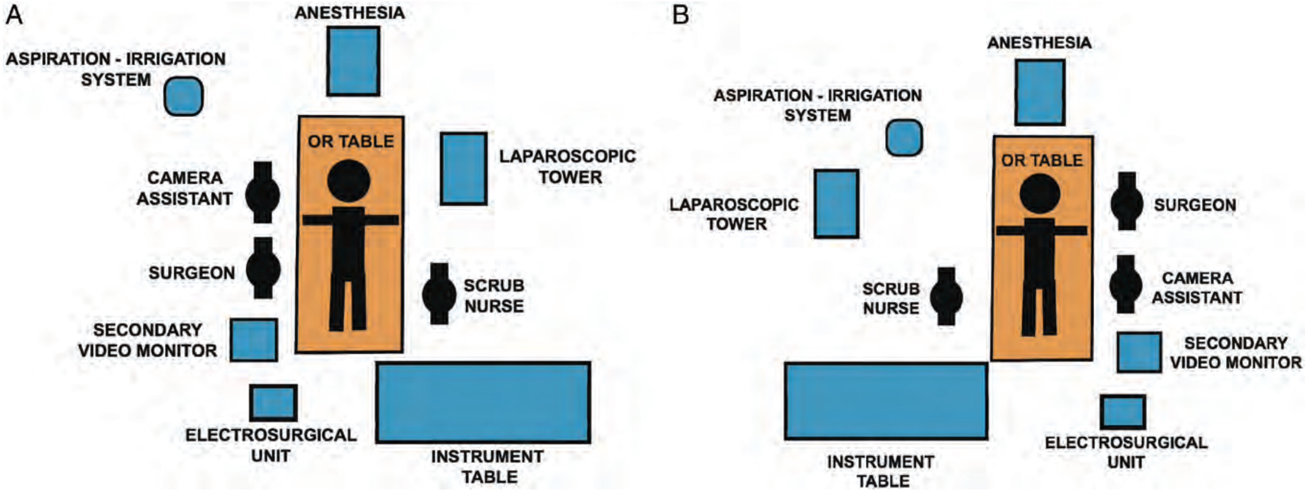
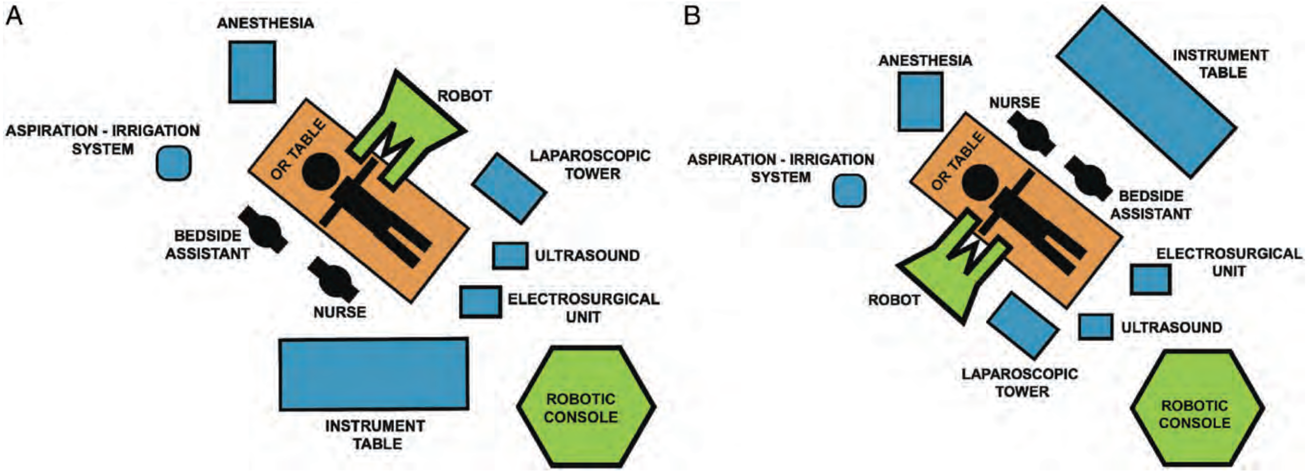

A
ANESTHESIA
ASPIRATION - IRRIGATION SYSTEM
OR TABLE
LAPAROSCOPIC TOWER
CAMERA ASSISTANT
SURGEON
SCRUB NURSE
SECONDARY VIDEO MONITOR
ELECTROSURGICAL UNIT
INSTRUMENT TABLE
B
ANESTHESIA
ASPIRATION - IRRIGATION SYSTEM
OR TABLE
LAPAROSCOPIC TOWER
SURGEON
SCRUB NURSE
CAMERA ASSISTANT
SECONDARY VIDEO MONITOR
INSTRUMENT TABLE
ELECTROSURGICAL UNIT

Figure 68.1 Operating room set-up. (A) Left-sided laparoscopic transperitoneal renal surgery. (B) Right-sided laparoscopic transperitoneal renal surgery.


A
ANESTHESIA
ROBOT
ASPIRATION - IRRIGATION SYSTEM
OR TABLE
LAPAROSCOPIC TOWER
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ULTRASOUND
NURSE
ELECTROSURGICAL UNIT
INSTRUMENT TABLE
ROBOTIC CONSOLE
B
INSTRUMENT TABLE
ANESTHESIA
NURSE
ASPIRATION - IRRIGATION SYSTEM
OR TABLE
BEDSIDE ASSISTANT
ELECTROSURGICAL UNIT
ROBOT
ULTRASOUND
LAPAROSCOPIC TOWER
ROBOTIC CONSOLE

Figure 68.2 Operating room set-up. (A) Left-sided robotic transperitoneal renal surgery. (B) Right-sided robotic transperitoneal renal surgery.

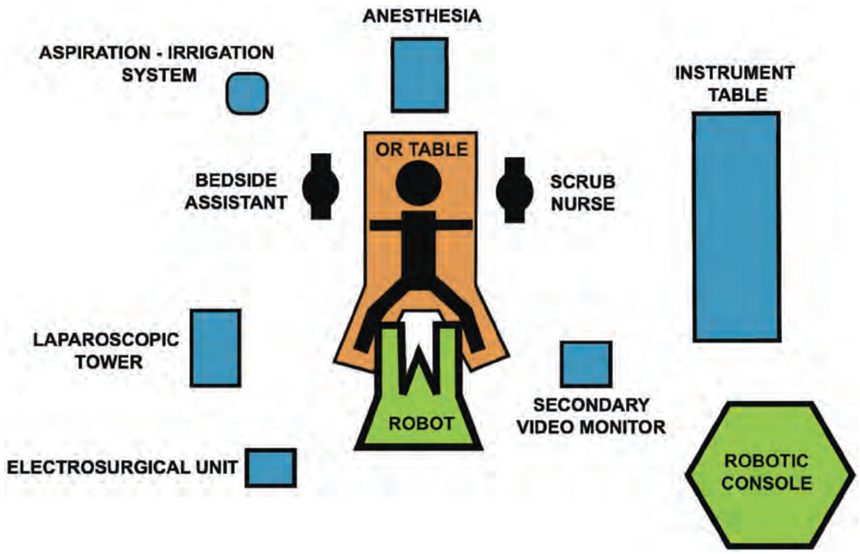
ANESTHESIA
ASPIRATION - IRRIGATION SYSTEM
INSTRUMENT TABLE
OR TABLE
BEDSIDE ASSISTANT
SCRUB NURSE
LAPAROSCOPIC TOWER
SECONDARY VIDEO MONITOR
ROBOT
ELECTROSURGICAL UNIT
ROBOTIC CONSOLE

Figure 68.3 Operating room set-up for robotic pelvic surgery.

enter from the contralateral side of the table or from the head or foot of the table. Additional lines from equipment, such as a Harmonic scalpel, LigaSure (Covidien, Boulder, CO, USA) or argon beam coagulator, should be arranged in an orderly fashion to prevent them from getting tangled during surgery. Pre-existing or improvised pockets in the laparoscopic drape can be helpful for organizing equipment.

During robotic procedures the surgeon console can be positioned in a corner of the operating room, depending on room configuration. In the newer generation robotic surgical systems, the optical viewer, arm rest, and foot pedals can be easily adjusted for surgeon comfort. For robotic renal surgery, the assistant is positioned on the side opposite the surgical site. For robotic pelvic surgery, the authors' preference is for the bedside assistant to sit or stand on the patient's right side with the scrub nurse on the patient's left side. One advantage of having the scrub nurse and assistant on opposite sides of the table is that the scrub nurse can be positioned close enough to the table to actively participate in the surgery, such as during Foley catheter manipulation and for applying perineal pressure. A disposable plastic instrument holder can be secured to the laparoscopic-assisted vaginal hysterectomy (LAVH) drape next to the bedside assistant for convenient intraoperative storage of frequently used instruments. This helps minimize instrument passage across the patient's body. Alternatively, a sterile Mayo stand can be positioned next to the bedside assistant as a "mini table" to hold the frequently used instruments. It should be noted that some surgeons prefer the bedside assistant to be located on the patient's left side, allowing the fourth arm to be placed on the patient's right side and the two grasping instruments to be used simultaneously. A second video monitor is helpful for the remainder of the operating room staff. If laparoscopic ultrasound is used, the screen should be placed within the assistant's direct line of vision.

Once the robotic and assistant ports are placed, the robot is docked. It is important to align the base of the slave unit with the camera port. This allows for proper docking of the robotic instruments in order to have adequate range of motion and to avoid arm collisions. With the daVinci Si Surgical System, it is important that the blue arrow on the camera arm be aligned within the "sweet spot" to ensure the slave unit is docked within the correct distance from the operating table to accommodate appropriate range of motion of all instruments.

Patient positioning

Laparoscopic renal surgery

In traditional open renal surgery, the patient is positioned in flank position in the lateral decubitus position with the kidney rest elevated and the table flexed. In contrast, laparoscopic transperitoneal renal surgery can be effectively performed with the patient in the modified flank position [3] (Figure 68.4). The patient is placed in the supine position with a 10 lb sandbag or gel roll under the ipsilateral side, creating a 30° rotation. The bottom leg is slightly bent and the top leg is left straight. Pillows are placed between the legs as a cushion and to slightly elevate the upper leg in line with the torso. The chest and hips are secured to the table with 3-inch silk tape. The ipsilateral arm is then padded and secured in a modified "sling" position, similar to the position used by orthopedics for clavicular fractures. The contralateral arm should be secured to an arm board. All pressure points are padded with corrugated foam or gel pads. Neither the kidney rest nor an axillary roll is necessary in this modified flank position. The table is then maximally rotated laterally, thus creating a true 90° angle relative to the horizontal. The lateral rotation of the bed should be tested prior to draping the patient and the anesthesia team should ensure patency of arterial and venous access. This positioning is ergonomic for the patient and surgeon.

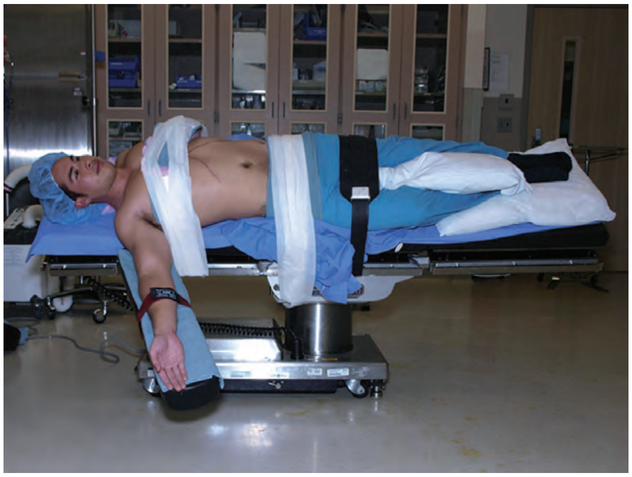

Figure 68.4 Patient positioned in modified flank position for laparoscopic and robotic transperitoneal renal surgery.

Positioning for retroperitoneal laparoscopic renal surgery is similar to that for open nephrectomy. The patient is placed in the full lateral position in the center of the table with the kidney rest elevated and the table flexed. An axillary roll is placed to prevent brachial plexus injury.

Bilateral lower extremity antiembolic stockings and pneumatic compression devices should be in place prior to induction of anesthesia. An upper body and/or lower intraoperative warming device should be placed before the patient is prepped and draped. There is debate about optimal surgical site preparation and preoperative antibiotics for prevention of incisional infections. A recent prospective randomized clinical trial comparing chlorhexidine–alcohol to povidone–iodine for surgical site preparation demonstrated a statistically significant reduction in both superficial and deep surgical incisional infections with the use of chlorhexidine–alcohol [4]. The entire abdominal wall should be prepped from the nipples to the pubis. The genitalia should be prepped in the field for minimally invasive nephroureterectomy and ureteral reimplant to allow for sterile Foley catheter placement on the field. Antibiotic prophylaxis should be administered within 60 min of the surgical incision. The American Urological Association's best practice policy statement on urologic surgery antibiotic prophylaxis is an excellent resource for selecting specific preoperative antibiotics [5]. Prior to insufflation, an orogastric tube and Foley catheter should be in place in order to decompress the stomach and bladder to avoid inadvertent injury to these hollow viscera.

Robotic pelvic surgery

For robotic pelvic surgery the patient is ultimately placed in a steep Trendelenburg position with the legs in a low lithotomy position (Figure 68.5). This position allows gravity to pull the abdominal viscera away from the operative field and the assistant to access the perineum and genitalia intraoperatively. The operating table is prepared with egg-crate foam taped to the table and a folded sheet placed under the egg-crate foam to facilitate securing the arms. The friction between the egg-crate foam and the patient's skin will help prevent cephalad slippage or movement when the table is in the full Trendelenburg position. Some centers advocate the use of a gel pad instead of egg-crate foam between the operating table and the patient's skin because of reports of chafing and skin breakdown. The patient is placed in the supine position with the buttocks at the end of the table break. Prior to induction of anesthesia, compression stockings and sequential compression devices are placed on the patient's lower extremities. The legs are placed in Allen Yellofin stirrups (Allen Medical Systems, Acton, MA, USA) with the knees flexed. The foot of the table is then lowered until it is perpendicular to the floor. Care should be taken to align the toe, knee, and opposing shoulder, to ensure the heels are touching the heel of the boot, and to check that the calves have adequate space to avoid popliteal artery occlusion, peroneal nerve injury [6], or the devastating complication of lower extremity compartment syndrome [7]. The anesthesiologist should evaluate the position of the patient's head before and after applying the Trendelenburg position in order to monitor for slippage. The arms are tucked at the patient's side with the preplaced sheet under the gel pad. Alternatively, arm sleds can be utilized to secure the arms without tension; however, excess arm compression can result in temporary neuropraxia. The fingertips are positioned at the anterolateral thigh. The elbows and wrists are protected with gel padding, and small foam rolls are placed in the patient's hands. Care should be taken to ensure that vascular lines and the pulse oximeter are properly functioning. The arms should be secured low enough for the prepped field to include the area lateral to the anterior superior iliac crest. Obese patients may require an arm board on the side of the table to support the arms. We do not recommend routine use of shoulder straps or taping the shoulders in a harness fashion because of the risk of brachial plexus injury [8, 9]. We recommend using foam-wrapped 3-inch cloth tape across the chest to prevent cephalad slippage in obese patients only. Care should be taken to ensure the chest tape does not impede mechanical ventilation.

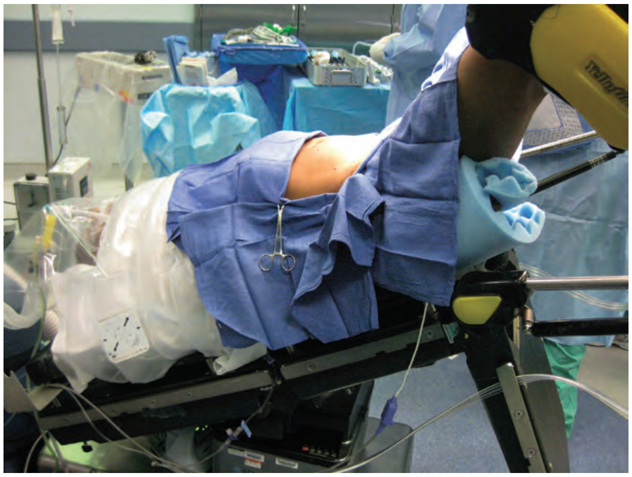

Figure 68.5 Patient positioning in low lithotomy with the full Trendelenburg position for robotic pelvic surgery.

The patient is then prepped and draped from the costal margin to the mid thighs, including the genitalia and perineum. Surgical site preparation and preoperative antibiotic prophylaxis recommendations are the same as for laparoscopic renal surgery with the exception of using povidone–iodine scrub and paint on the genitalia. An LAVH drape is useful for robotic pelvic surgery as it is a combination leg and laparoscopic drape. The field is established such that the bedside assistant can have access to the perineum and genitalia for intraoperative application of perineal pressure during initial anastomotic suture placement and for Foley manipulation. A 20F Foley catheter is placed sterilely on the field and the anesthesia team should place an orogastric tube.

After initial insufflation and port placement, the patient should be placed in a steep Trendelenburg position. The robot is brought in for docking between the legs. The Allen Yellowfin stirrups should be low enough to accommodate the robot. Once the robot is docked, there should be no additional manipulation of the table position.

Positioning pitfalls

Suboptimal positioning not only can lengthen operative times and lead to surgeon frustration, but can lead to devastating complications. Despite proper patient positioning and preparation, patient injuries have been reported as a consequence of positioning during laparoscopic and robotic surgeries [6, 10]. Wolf *et al*. reported on 1651 procedures that resulted in 46 neuromuscular injuries in 45 patients (2.7%), including abdominal wall neuralgia, extremity sensory deficit, extremity motor deficit, clinical rhabdomyolysis, shoulder contusion, and back spasm. Patients with rhabdomyolysis were more often male, were heavier, and underwent longer procedures. Patients with motor deficits were older. Preexisting nerve dysfunction predisposes patients to motor nerve injury.

It is important for the surgeon to remain comfortable throughout the procedure in order to avoid pain or fatigue. Interestingly, 28% of surgeons in the 18 academic institutions included in Wolf *et al*.'s study reported frequent neck pain and 17% reported frequent shoulder pain [6]. Measures taken by surgeons to alleviate neuromuscular strain included lowering the table maximally, using lifts on the floor, altering the manner in which they held instruments (without fingers through the handles), and altering the position of the monitors.

A devastating complication of robotic pelvic surgery is lower extremity compartment syndrome, which can occur when the patient is placed in Allen Yellofin stirrups in the extreme Trendelenburg position. This complication may require lower extremity fasciotomy [7, 11]. Proper positioning is key to prevention, specifically ensuring the patient's ankle, knee, and contralateral shoulder are aligned in the stirrup, and that gel pads are used directly in contact with the patient's skin to avoid cephalad slippage while in the Trendelenburg position. A high index of clinical suspicion will facilitate early recognition and prompt treatment.

There have been reports of patients developing ischemic optic neuropathy after laparoscopic radical prostatectomy, thought to be a result of a combination of long operative time and the Trendelenburg position [12]. Intraocular pressure measurements in surgical patients confirmed a higher intraocular pressure in patients in the Trendelenburg compared to the supine position [13]. However, the direct clinical consequences of sustained elevated intraoperative intraocular pressures are not known.

Positioning for other robotic procedures

Other robot-assisted laparoscopic pelvic surgery

Positioning for a robot-assisted laparoscopic radical cystectomy and for robot-assisted ureterovesical reimplant is similar to that for robot-assisted laparoscopic radical prostatectomy. The only difference is shifting port placement slightly cephalad to allow for proximal ureteral dissection and for extended bilateral pelvic lymphadenectomy. The 12-mm camera port is placed 2 cm above the umbilicus and the two robotic ports are placed approximately at the level of the inferior border of the umbilicus.

Transperitoneal robot-assisted laparoscopic renal surgery

Positioning for robot-assisted laparoscopic kidney surgery is similar to that for the pure laparoscopic approach. Depending on operating room configuration, the operating table may need to be rotated 90º to accommodate docking the robot. The robot is docked from the ipsilateral side of the table in a direct line between the camera port and the renal hilum.

Conclusions

Time spent properly setting up the operating room and positioning the patient is invaluable. The entire urologic team should be involved in the process with the goal of optimizing outcomes.

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CHAPTER 69

Anesthetic Considerations during Laparoscopic and Robotic Surgery

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Introduction

The use of laparoscopic and robotic techniques in urologic surgery is growing rapidly. Clearly, laparoscopy and robotic surgery provide some important advantages over traditional open techniques, but they also produce new challenges. Patient selection, type of anesthesia, monitoring requirements, and technical challenges created by positioning need to be discussed in advance by the surgeon and anesthesiologist. This chapter reviews the anesthetic and monitoring choices available for laparoscopic surgery and the physiologic changes specific to laparoscopy. The management of pain, nausea, and vomiting are also discussed.

Overview of anesthesia

Anesthetic agents

The choice of anesthetic agents for any surgery depends upon the patient population, duration of surgery, and desire to maintain hemodynamic stability through the surgical stimulus, with an emphasis on minimizing known postoperative side effects, such as pain and postoperative nausea and vomiting (PONV).

Induction of anesthesia

Typical drugs used for induction include sedative hypnotics such as propofol or etomidate. Synthetic narcotics such as fentanyl, remifentanil, or sufentanil are recommended for patients who are unable to tolerate any significant hemodynamic instability during the induction of anesthesia. Depolarizing (succinylcholine) or nondepolarizing (rocuronium, vecuronium) muscle relaxants are also used to ensure an optimal condition for intubation.

Maintenance of anesthesia

Successful maintenance of anesthesia entails a quiescent patient and surgical field, as well as minimal hemodynamic variations associated with pneumoperitoneum or surgical stimulus. The use of inhalational agents, muscle relaxants, narcotics, sedative hypnotics, and antihypertensives, in combination, achieves the goal of balanced anesthesia.

Emergence

The patient's safe emergence and recovery requires full reversal of muscle relaxation. This is typically achieved using a cholinesterase inhibitor such as neostigmine or edrophonium. PONV can be minimized by the use of the selective serotonin 5-hydroxytryptamine 3 (5-HT3) receptor antagonists ondansetron or dexamethasone. Aprepitant, a neurokinin-1 (NK1) receptor antagonist, may be used to alleviate PONV in high-risk patients [1].

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Avoiding the use of nitrous oxide has the dual effect of minimizing incidence of PONV as well as optimizing the view of the surgical field by attenuating bowel distention.

Anesthesia techniques

General anesthesia with an endotracheal tube and controlled ventilation is typically used for most laparoscopic procedures, but the use of local anesthesia and regional anesthesia has also been reported.

General anesthesia

General anesthesia with a secured airway and controlled ventilation is considered the safest technique, particularly for cases requiring long periods of sustained pneumoperitoneum. During the insufflation of CO_2, controlled ventilation can be effectively implemented to adjust for increases in end-tidal CO_2 ($PetCO_2$). This is achieved by adjusting the tidal volume and respiratory rate to maintain $PetCO_2$ preferably between 35 and 40 mmHg. The use of a laryngeal mask airway with a spontaneously breathing patient can be considered for cases of shorter duration with relatively low insufflation pressures [2]. Benefits include the avoidance of the use of muscle relaxants and tracheal irritation from intubation. This technique is often seen in the pediatric population in which a transinguinal diagnostic laparoscopy may be used to evaluate the need for surgical intervention on the contralateral side of the known defect.

Local anesthesia

Local anesthesia with sedation can be a viable anesthetic option employed for laparoscopic procedures. The benefits include quicker recovery, decreased incidence of PONV, earlier diagnosis of complications, and fewer hemodynamic changes [3, 4]. The technique is not commonly used, however, as it can also lead to hypoventilation and desaturation secondary to the combined effects of increased intra-abdominal pressure and sedation [5].

Regional anesthesia

Regional spinal or epidural techniques have been developed as an alternative to general anesthesia for surgical procedures using laparoscopy. The benefits include decreased incidence of PONV, decreased postoperative pain, and potentially a shortened course to discharge. Disadvantages include the need for a cooperative patient and shoulder pain associated with pneumoperitoneum-induced diaphragmatic irritation. Careful patient selection, surgeries of short duration, and surgical dissection protocols are necessary when considering the use of regional anesthesia [6–8].

Overview of monitors and invasive lines

Blood pressure, electrocardiogram, heart rate, end-tidal CO_2, temperature, and pulse oximetry must be monitored during laparoscopy. Hemodynamic variations that occur as a result of pneumoperitoneum can be detected and corrected in a timely manner.

The use of invasive monitoring may be considered for patients presenting with concomitant cardiopulmonary disease. Placement of an arterial line can be employed for continuous blood pressure monitoring and the acquisition of blood samples for acid–base and electrolyte analysis. Although this level of monitoring is valuable, it provides only indirect evidence of the hemodynamic changes induced by the pneumoperitoneum. Also, changes in intra-abdominal and intrathoracic pressures can make the use of central venous monitoring unreliable. The use of transesophageal echocardiography can be used to guide fluid management in patients with pre-existing cardiopulmonary disease. Indications for placement of invasive monitors are neither absolute nor all-inclusive. Examples of cases who benefit from the use of an arterial line and/or central line include: when noninvasive monitoring is not possible or unreliable; in patients at significant risk for hemodynamic collapse during induction of anesthesia; in patients with severe cardiopulmonary disease, such as pulmonary hypertension, severe emphysema, or severe cardiomyopathy; in patients with labile blood pressure; in cases where the surgeon and/or anesthesiologist are concerned about blood loss or fluid shifts; in cases who require multiple blood samples; and in cases who will likely need potent vasoactive agents. Additional examples of situations that benefit from the insertion of a central line include patients with little to no peripheral access and patients who will need a central line postoperatively for intravenous alimentation. Alternatively, the routine use of invasive lines is not warranted in healthy patients having laparoscopic surgery by an experienced surgeon when significant blood loss or fluid shifts are not expected. Also, duration of case is not, as a single variable, enough of an indication for use of invasive monitoring lines. Noninvasive blood pressure monitoring and peripheral intravenous access can be used safely for long periods of time in healthy patients undergoing surgery with minimal blood loss or fluid shifts.

In some instances where the indication for an invasive monitoring line is equivocal, the ability to place the line during the case has to be taken into account. For example, if both arms are tucked under the drapes during positioning, providing no access to the arms during the case, the anesthesiologist may need to lower their threshold for placing an arterial line prior to positioning the patient. Ultimately, the decision to use invasive monitoring lines needs to be made on a case–by-case basis, which is best done by having a preoperative discussion between the anesthesiologist and surgeon.

Laparoscopy and robotic surgery

Physiologic changes caused by insufflation

Pulmonary changes

The effects of instituting pneumoperitoneum on pulmonary physiology is a combination of multiple factors, including mechanical effects, type of gas used to create pneumoperitoneum, patient size, and the existence of any pulmonary pathophysiology with which the patient may present. Diaphragmatic excursion becomes limited as intra-abdominal pressure increases, resulting in decreased lung capacity and compliance with eventual ventilation–perfusion mismatching and shunting [9–11]. Decreases in vital capacity, functional residual capacity, total lung volume, and pulmonary compliance are specifically seen along with increases in peak inspiratory pressures and ventilation–perfusion mismatch [12–14]. The effects of the induction of general anesthesia and pre-existing body habitus can further compound these effects. It is well known that the induction of general anesthesia leads to decreases in the aforementioned lung volumes. Patients who are obese can also present pre-existing atelectasis and decreased lung volumes.

Although CO_2 is the gas most frequently used, other gases such as helium, argon, and nitrous oxide have been used in the past, each with its own benefits and negative consequences on pulmonary physiology. Nitrous oxide is combustible and will diffuse into an air-filled space 34 times faster than nitrogen will diffuse out of that space. Therefore, it is a potential fire hazard and can cause bowel distention, which will diminish surgical exposure. Helium and argon have also been tested in animal models and humans. They are both inert gases and not combustible, but are relatively insoluble and can increase the risk of catastrophic gas emboli [15]. CO_2 has been found to be the safest gas to use in most patients presenting for surgery requiring laparoscopy. It is nonflammable and very soluble, making it easily absorbed into the circulation and eliminated via the lungs. Biochemically, the gas absorption that occurs during insufflation can lead to an imbalance with respect to CO_2 production and elimination. Normal CO_2 production in the average adult is approximately 150–200 mL/min [16, 17]. CO_2 absorption into the systemic circulation via the peritoneum during laparoscopy has been measured at a rate of about 14–48 mL/min [18–21]. As such, adjustments need to be made in minute ventilation, either via increasing tidal volume or respiratory rate, to minimize hypercarbia. If left unchecked, the hypercarbia and resultant respiratory acidosis can lead to depressed cardiac function and arrhythmias. Clinical studies have suggested that subcutaneous emphysema, increased intra-abdominal pressure, extraperitoneal insufflation, and prolonged duration of insufflation can increase the rate of CO_2 absorption.

It is also important to note that not all CO_2 is effectively eliminated during surgery. Some CO_2 can be sequestered, particularly in the skeletal system, and slowly eliminated throughout the postoperative period [22]. This can be of particular concern in patients with pre-existing cardiopulmonary dysfunction, who may not tolerate excessive hypercarbia. Neuberger *et al*. suggested in a study that switching to another gas such as helium after the initiation of pneumoperitoneum would minimize the hypercarbia and may be of some benefit in patients with chronic obstructive pulmonary disease (COPD) or morbid obesity [15]. Clinical studies have suggested that subcutaneous emphysema, increased intra-abdominal pressure, extraperitoneal insufflation, and prolonged duration of insufflation can increase the rate of CO_2 absorption [23].

Cardiac changes

The hemodynamic consequences of pneumoperitoneum and the resultant increased intra-abdominal pressure include a decrease in cardiac output, increase in mean arterial pressures (MAPs), increase in systemic vascular resistance (SVR), and increase in pulmonary vascular resistance. Cardiac output and cardiac index have been reported to initially increase at intra-abdominal pressures less than or equal to 10 mmHg, secondary to increased venous return as a function of autotransfusion. Decrease in cardiac output can be seen as intra-abdominal pressures increase above 20 mmHg [24]. Other factors that affect cardiac output include volume status, patient position, the sympathoadrenal effects of increased intra-abdominal pressures and CO_2 insufflation, and vagal reflexes as a function of peritoneal distention. Hypovolemic patients tend to have a more exaggerated drop in cardiac output in response to increases in intra-abdominal pressure compared to patients who are euvolemic prior to the onset of pneumoperitoneum.

Patients in the Trendelenburg position can exhibit a modest increase in cardiac output. A decrease in cardiac output can conversely be seen in the reverse Trendelenburg position, secondary to decreased venous return. Intra-abdominal pressure decreases venous return secondary to caval compression [25] and increases venous resistance [26, 27]. These observations are supported by a reduction in left ventricular end-diastolic volume (LVEDV) measured during transesophageal echocardiogram (TEE) [28]. An increase in cardiac filling pressure as a consequence of an increase in intrathoracic pressure is also seen during laparoscopy. As a result, right atrial pressure and pulmonary artery occlusion are unreliable to ascertain cardiac filling pressure [27, 29, 30]. The increases in SVR and MAP are believed to be caused by mechanical and neurohormonal factors [31]. Increases in catecholamine production resulting from surgical stress and increases in intra-abdominal pressure are known to occur. Early stages of hypercarbia also have a sympathomimetic effect, causing the release of catecholamines. As hypercarbia progresses, acidosis becomes more profound and a cardiodepressant effect predominates. The renin–angiotensin system and vasopressin are additionally suspected to contribute to the increase in SVR [29, 32–36].

Renal changes

Oliguria is known to occur during laparoscopic surgery. Urine output in the setting of pneumoperitoneum may not be a reliable indicator of fluid status during laparoscopic surgery. Mistakenly, relying solely on urine output for fluid management may lead to fluid overload.

There are many factors that can cause oliguria, including decreased cardiac output, renal vein compression, ureteral obstruction, renal parenchymal compression, and systemic hormonal effects [37, 38]. Intra-abdominal pressure above 15 mmHg has been shown to consistently cause a decrease in urine output. Miki *et al*. conducted a human study in which low insufflation pressure of 4 mmHg was used along with retraction devices during laparoscopic cholecystectomy [39]. They found that urine output, renal blood flow, and glomerular filtration rate (GFR) remain unchanged [39, 40]. Direct renal parenchymal compression was purported to mimic a Page kidney effect [40]. Razvi *et al*. placed a pressure cuff on canine kidneys, applying pressures of 15 mmHg. They found a decrease in urine output, GFR, and effective renal blood flow [41]. An increase in levels of serum aldosterone, along with an increase in urine potassium and a decrease in urinary sodium, have been reported in animal models [42]. This also supports the theory of the Page kidney effect being a major cause of the intraoperative oliguria seen during laparoscopic procedures.

A decrease in cardiac output has been disproven as a substantial cause of oliguria because normalization of cardiac output with fluid resuscitation does not result in an increase of urine output [37, 38].

Ureteral obstruction is unlikely to cause oliguria because placement of ureteral stents during pneumoperitoneum does not lead to an increase in urine output [43]. Intraoperative urograms have also confirmed the absence of ureteral obstruction during pneumoperitoneum in animals [42].

These intraoperative effects tend to resolve in the postoperative period among healthy patients, but those with pre-existing renal dysfunction may have cause for concern. Cisek *et al*. created an animal model in which renal insufficiency had been simulated via renal reductive surgery [44]. The animals were subjected to prolonged periods of pneumoperitoneum with resultant decreases in urine output, GFR, and renal blood flow despite hydration. Acute renal failure was noted to last 1 week with values returning to the baseline level of renal insufficiency previously created with no long-term impact on renal function [44].

Elevated intra-abdominal pressures may also act to cause oliguria by stimulating increases in endogenous catecholamines. Mikami *et al*. showed that insufflation pressures at or above 20 mmHg resulted in increased catecholamine levels [45]. Endothelin has been shown to increase during pneumoperitoneum and in response to renal vein compression. Compression of a unilateral renal vein leads to a decrease in the GFR and urine output in both kidneys, and is associated with elevated renal vein endothelin concentrations, implicating it as a contributing factor to the oliguria observed during long laparoscopic cases [40, 46]. In animal studies using vasopressin antagonist, renal function improved in comparison to control groups. This implies that vasopressin plays a causal role in the development of oliguria during laparoscopic procedures [47].

Altering the temperature of the insufflant has been shown to partially attenuate the oliguric effects seen with laparoscopic procedures [48]. Backlund *et al*. compared the use of warm (37°C) CO_2 with that of room-temperature CO_2. Higher core temperature, urine output, and cardiac index were observed [48]. This suggests that regional vasodilatation of the renal vasculature may help restore renal blood flow and urine output. The use of warm insufflants to aid in the preservation of urine output may be of benefit to patients with pre-existing cardiac or renal dysfunction by making fluid management more predictable, especially during long cases.

Cerebral blood flow changes

Cerebral hemodynamic variability during laparoscopy can be affected by multiple factors. Cardiovascular changes, alterations in $PaCO_2$, patient position, and raised intra-abdominal and intrathoracic pressures (with or without a rise in $PaCO_2$) can all affect cerebral perfusion dynamics [49]. In an animal study, Rosenthal *et al*. showed significant increases in intracranial pressure at intra-abdominal pressure above 8 mmHg. It is postulated that this is secondary to compression of the large intra-abdominal caval vessels. This leads to an increase in central venous pressures as a result of a decrease in venous drainage from the central nervous system. Placing the patient in the head-down position can also augment this effect.

Cerebral blood flow velocity increases during CO_2 pneumoperitoneum as a result of an increase in $PaCO_2$ [50–52]. Fujii *et al.* studied the effects of intraperitoneal CO_2 insufflation on middle cerebral arterial blood flow velocity in 10 patients during laparoscopic cholecystectomy [51]. A positive correlation between cerebral blood flow velocity and $PaCO_2$ was seen. The hypercapnia associated with CO_2 pneumoperitoneum causes direct cerebral vascular vasodilatation that can lead to increased intracranial pressure. Hyperventilating the patient may attenuate this.

Endocrine response

Many studies have been conducted comparing open and laparoscopic procedures and the stress response associated with each. It has been shown that laparoscopic procedures produce a much lower stress response compared to open procedures. Increases in MAP and SVR are seen during laparoscopy, however. Elevated levels of antidiuretic hormone have been correlated with increases in MAP and SVR during laparoscopic procedures [49]. Furthermore, elevated levels of plasma renin and aldosterone have been correlated with an increase in MAP [35]. Levels of cortisol, human growth hormone, epinephrine, and norepinephrine were found to increase after deflation of pneumoperitoneum. Increases in vasopressin and other endogenous catecholamines such as epinephrine and norepinephrine have been associated with changes in intra-abdominal and intrathoracic pressure [32]. Plasma levels of cortisol and catecholamine are elevated during laparoscopic procedures. Laparoscopy allows for a decrease in acute-phase reactants normally seen during the surgical stimulus. C-reactive protein and interleukin (IL)-6 are significantly lower compared to open procedures [53–55]. The metabolic and inflammatory responses are muted. There is less hyperglycemia and leukocytosis [53, 54].

Effects of common positions during laparoscopy

It is well known that many of the protective reflexes that prevent wide swings or variations in a patient's hemodynamic response to positional changes are blocked or attenuated upon the induction of anesthesia. Some of these reflexes include afferent aortic and carotid baroreceptors, which, under normal circumstances, respond to changes in preload by mediating and modulating sympathetic outflow and vasomotor tone. The result is a well-controlled hemodynamic profile in which blood pressure is maintained and perfusion of vital organs is preserved regardless of position. Changes in position can cause significant hemodynamic compromise during surgery under general anesthesia, however. Changes in pulmonary mechanics are further exacerbated by positional changes under general anesthesia. These pulmonary changes include a decrease in tidal volume, functional residual capacity, and lung compliance, as well as an increase in closing volume, leading to atelectasis and intrapulmonary shunting.

Trendelenburg

Trendelenburg position can increase venous return, central venous pressure, intracranial pressure, and intraocular pressure. It can also improve surgical exposure, but can result in significant cardiopulmonary compromise. A prolonged Trendelenburg position postoperatively may cause soft tissue edema in and around the airway, leading to airway complications. The Trendelenburg position increases the work of breathing in the spontaneously breathing patient, which leads to a decrease in functional residual capacity, tidal volume, and pulmonary compliance. Atelectasis with intrapulmonary shunting may also occur. Controlling tidal volume and respiratory rate under general anesthesia minimizes the aforementioned effects, however.

Reverse Trendelenburg

The reverse Trendelenburg position causes the most significant hemodynamic perturbations when instituted along with pneumoperitoneum [49]. It decreases venous return to the heart, leading to profound hypotension. Concern about cerebral perfusion pressure is warranted. The resultant decrease in blood pressure and MAP can lead to cerebral hypoperfusion. Cerebral perfusion pressure is autoregulated between MAPs of 50 mmHg and 150 mmHg in order to keep tight control on cerebral blood flow under normal circumstances. This protective autoregulatory mechanism is lost when MAPs fall outside of this range, however, and cerebral perfusion becomes entirely flow dependent. Cerebral ischemia may occur during hypotensive episodes. Cerebral hyperperfusion may also occur during hypertensive episodes. This hemodynamic instability may put the patient at risk for cerebrovascular hemorrhagic and ischemic events. Patients with pre-existing abnormal cerebral autoregulatory mechanisms, such as those with chronic hypertension, a history of cerebrovascular accidents, or with carotid occlusive disease, may require higher than normal cerebral perfusion pressures as their autoregulatory curves may be shifted to the right.

Decreased femoral vein flow occurs with CO_2 insufflation and high intra-abdominal pressures, and is exacerbated by the reverse Trendelenburg position [56, 57]. This can increase the risk of deep vein thrombosis (DVT) [58]. The use of intermittent compression devices on the lower extremities can help to reverse the effects of these physiologic changes, thereby minimizing the risk of the development of DVT [58, 59].

Lateral decubitus

The lateral decubitus position is good for procedures requiring retroperitoneal exposure. Care must be taken to keep the head in the neutral position and to avoid pressure on the dependent ear and eye. Stretch or pressure injuries to the brachial plexus can be avoided by the use of an axillary roll placed just below the axilla. It is also prudent to monitor the pulse in the dependent arm via pulse oximetry to detect compression of neurovascular structures. It should also be remembered that this position can lead to ventilation–perfusion mismatch and changes in pulmonary compliance for the dependent lung, as well as overinflation and potential barotrauma to the nondependent lung. A certain amount of flex may be applied to these patients, usually occurring at the iliac crest, in order to maximize exposure. If a kidney rest is used, care must be taken to ensure proper placement at the iliac crest in order to avoid compression of the inferior vena cava.

Lithotomy

The lithotomy position can cause an increase in cardiac output, intracranial pressure, and central venous pressure. It can conversely cause a decrease in lung compliance and tidal volume. The loss of the natural lordotic curvature of the lumbar spine can lead to back pain after prolonged procedures in the lithotomy position. Care must be taken to avoid injury of the common peroneal nerve, the risk of which increases in patients with high body mass index, patients who smoke, and with an increased duration of surgery [60]. Lower extremity compartment syndrome can be seen as a result of decreased perfusion, resulting in ischemia, edema, and rhabdomyolysis. Prolonged surgical time in the lithotomy position can increase the risk of this complication, thus lowering the leg periodically in long procedures can help to prevent this from happening [61–64].

Nerve Injury

There is a risk of nerve injury with any position in which a patient is placed. A review of 81 000 anesthetics performed between 1987 and 1993 showed the incidence of nerve injury to be roughly 0.11% [65]. Ulnar nerve injury has the highest rate at 28%, followed by brachial plexopathy (20%), lumbosacral injury (16%), spinal cord injury (13%), and sciatic nerve injury occurring in 5%, which also includes common peroneal nerve injuries [66]. The American Society of Anesthesiologists Task Force Consensus Findings on Prevention of Perioperative Peripheral Neuropathies showed no clear etiology for ulnar neuropathies and concluded that the cause was multifactorial [67]. It suggested that, when tucked, the upper extremities should be appropriately padded in the neutral position with the palms toward the body. If the upper extremities are abducted, they should be kept in the supinated or neutral position with the palms toward the body [67]. Brachial plexus injuries occur as a result of stretching if the arms are abducted greater than 90° from the body for a prolonged period of time or compression, as can be seen in the lateral decubitus position. The use of an axillary roll is customarily employed to minimize the risk of this complication. Injuries to the sciatic nerve and common peroneal nerve commonly occur in the lithotomy position. Stretching of the nerve by excessive or prolonged external rotation of the leg, hyperflexion of the hips, or extension of the knee is the most frequent cause of sciatic nerve injury. Common peroneal nerve injuries are mostly due to compression of the nerve between the fibular head and the leg support frame.

Specific anesthetic considerations

Fluid management

Compared to open procedures, laparoscopic procedures tend to cause less fluid shifts and insensible losses. There is a decrease in urine output at intra-abdominal pressures greater than 10–15 mmHg, which can predispose patients to fluid overload during long laparoscopic procedures. Intraoperatively, it is advisable not to rely solely on urine output for fluid management. Volume status should be optimized prior to insufflation, if possible. For fluid replacement during the procedure, maintenance of fluid in the range of 5 mL/kg/h plus appropriate replacement for blood loss is considered a good method for fluid resuscitation without causing fluid overload [24, 68].

Gas embolism

Gas embolism, although rare, is usually seen immediately after insufflation and is caused by gas bubbles entering the systemic circulation and causing cardiovascular collapse. Symptoms include hypoxemia, hypercarbia, decreased cardiac output, pulmonary edema, increased airway pressures, hypotension, jugular venous distention, and dysrhythmias. Arterial embolization through a patent foramen ovale may occur if right heart pressures exceed left heart pressures. The incidence of venous gas embolism (VGE) has been estimated to be between 0.002% and 0.08% [24], although clinically detectable VGE may occur in as many as 0.59% of laparoscopic cases when careful surveillance is used [30]. A characteristic millwheel murmur can be auscultated. Widening of the QRS complex with a right heart strain pattern on electrocardiography (ECG) can also be seen.

Successful treatment requires quick intervention, including desufflation, ventilation with 100% FIO_2, steep head-down tilt with the right side up, and other supportive measures. Outcomes depend on the type of gas used. Air, which is 80% nitrogen, is resorbed very slowly in blood. CO_2 is 47 times more soluble than nitrogen. Graff *et al*. found the LD50 of CO_2 to be five times that of air when injected intravenously in dogs [69]. Helium as an alternative to CO_2 is even less soluble than nitrogen, however. Intravenous injection of helium (5–10 mL/kg) was lethal on four of six occasions in canine experiments, while the same amount of CO_2 was followed by hemodynamic recovery within 2 min in all cases [70]. Argon VGE during laparoscopic use of an argon beam coagulator has been reported. Helium and argon should therefore not be used for initial insufflation, but their use is possible in order to avoid hypercapnia after pneumoperitoneum via CO_2.

Subcutaneous emphysema

Subcutaneous emphysema occurs when gas leaks into extraperitoneal tissue planes. Etiologies include incorrect insufflation needle placement, excessive intra-abdominal pressures, malfunctioning equipment, or leaks around a laparoscopic port placed with an open technique. Extraperitoneal gas leads to increased gas absorption, which can manifest in the subcutaneous compartment as well as the thoracic cavity. Pneumomediastinum, pneumothorax, and pneumopericardium can inhibit cardiac filling and limit lung excursion.

Logistic considerations in urologic robotic surgery

The use of robotics in urologic surgery first began in the late 1980s when a robotic frame was developed for transurethral resection of the prostate [71]. There have been improvements made by several different companies over time with respect to complexity of the system. The da Vinci Robotic Surgical System is currently the primary system used. Procedures that use the da Vinci systems include radical prostatectomy, radical cystectomy, radical and simple nephrectomy, live donor nephrectomy, pyeloplasty, and adrenalectomy [71].

There are concerns specific to laparoscopic robotic surgery that should also be borne in mind. The patient's proximity to the robotic apparatus makes access to the upper extremities particularly challenging. Appropriate venous access should be obtained prior to the patient's final positioning. After careful consideration of the type of surgery, operative time, and experience of both surgeon and anesthesiologist, invasive monitoring such as an arterial line or a central venous pressure line may be placed prior to positioning the patient (see above).

Once in position and the patient is prepped and draped, surgery commences and instruments are connected to the robotic arms. It is imperative that the patient does not move once the instruments are inside them. Any movement can cause trauma to the patient. An intermediate- or long-acting nondepolarizing muscle relaxant such as vecuronium or pancuronium should be utilized to maintain adequate muscle relaxation throughout the case.

Careful attention should be paid to positioning, particularly during long cases. Positions such as Trendelenburg and low lithotomy carry increased risk for brachial plexus and lower extremity nerve injury (see above). The Trendelenburg position along with high intra-abdominal pressures for greater than 4 h can lead to airway edema. This should be kept in mind during the emergence and extubation period. Ensuring that there is an appropriate leak around the deflated endotracheal tube cuff and checking for any significant degree of scleral edema may help guide the decision process to extubate the patient immediately after surgery or not. Other considerations to guide this decision include concerns regarding fluid status, acid–base abnormalities, hypothermia, or general unexplained hemodynamic instability. As previously mentioned, fluid management should be carefully assessed and judiciously administered during long laparoscopic procedures, such as when robotic techniques are employed. Being mindful of the effects of pneumoperitoneum, positional changes, perioperative fluid status, preexisting renal disease, and temperature on urine output can help to avoid fluid overloading these patients.

Hypothermia during these cases can cause many problems in addition to possible oliguria. Coagulation defects and wound infection are also two well-known side effects associated with mild hypothermia [72, 73]. Postoperative alopecia after long surgical cases under anesthesia is also a risk. Ischemia to the hair follicles secondary to hypothermia or hypoperfusion is a causative factor [74].

To minimize prolonged periods of pressure at any one point of the head, care must be taken to pad and protect the occipital region and to rotate the head periodically. Back pain associated with long surgical times in the supine or lithotomy position have been documented and is suspected to be secondary to loss of the normal lordotic curve and decreased tone of the paraspinous muscles [74].

Anesthesia for high-risk patients

The value of laparoscopic procedures has increased over the last decade. This has become particularly apparent in urology. Advances in this area now routinely include laparoscopic varicocelectomy, hernia repair, adrenalectomy, partial adrenalectomy, renal pelvis or ureter percutaneous stone retrieval, radical prostatectomy, extra-adrenal pheochromocytoma, nephropexy, pyeloplasty, nephrectomy, partial nephrectomy, and cystectomy. Considerable advances in robotic technology have also yielded important tools for performing some of these surgeries.

Many patients undergoing minimally invasive urologic laparoscopic surgery have coexisting diseases. As a result, progressively older patients with corresponding pulmonary, renal, and cardiovascular comorbidities, as well as morbidly obese and pregnant patients, are now undergoing advanced laparoscopic surgery. Detailed knowledge of the respiratory and hemodynamic pathophysiology induced by CO_2 pneumoperitoneum and extremes of patient positioning is necessary to administer safe anesthesia to such patients.

Cardiac patients

Significant hemodynamic changes during pneumoperitoneum raise the question of tolerance of these changes among cardiac patients. Patients with cardiac disease are at an increased risk of developing myocardial ischemia during laparoscopy due to increase in myocardial wall tension caused by increased MAP and SVR [75]. Risk for myocardial ischemia may be exacerbated by insufficient tissue oxygen delivery manifested by a reduction in mixed venous oxygen saturation caused by a decreased cardiac index [75]. Preoperative evaluation may include echocardiography. Patients with severe congestive heart failure and terminal valvular insufficiency are more prone to develop cardiac complications than patients with ischemic cardiac disease during laparoscopy [50]. Intraoperatively, arterial blood pressure, heart rate, ECG, capnometry, and pulse oximetry must be continuously monitored. Pulmonary artery catheterization may be additionally useful in monitoring mixed venous oxygen saturation and cardiac index. TEE may be necessary to assess regional wall motion abnormalities, filling volumes, and ejection fractions [76]. Preload augmentation prior to pneumoperitoneum may be necessary. The magnitude of decrease in cardiac index is directly related to insufflation pressure [76]. Slow and gradual abdominal insufflation to a maximum pressure of 10 mmHg followed by a limited 10° head-up tilt has been associated with cardiovascular stability [77]. Hemodynamic monitoring should be continued in the postanesthesia care unit (PACU). The hyperdynamic state developing after laparoscopy could conceivably lead to a precarious hemodynamic situation in patients with cardiac disease. Increased oxygen demand is also observed after laparoscopy. Therefore, oxygen should be administered postoperatively, even to healthy patients [78].

Patients with pulmonary dysfunction

Considerable CO_2 absorption can occur during laparoscopic surgery (see above). The absorbed CO_2 can have deleterious effects in patients with pre-existing pulmonary dysfunction. Reduced compliance also impedes adequate pulmonary gas exchange and may predispose a patient to pneumothorax and pneumomediastinum [12, 79, 80]. Preoperative pulmonary function testing should be performed, including arterial blood gas analysis. Under normal circumstances, end-tidal CO_2 can be used to estimate the $PaCO_2$. The correlation between end-tidal CO_2 and $PaCO_2$ during laparoscopic procedures may be poor because of a reduced cardiac index and increased ventilation–perfusion mismatch. As such, intraoperative measurement of inspiratory plateau pressure and serial $PaCO_2$ are recommended. If refractory hypoxemia, hypercapnia, or high airway pressures occur, the pneumoperitoneum should be released, followed by slow reinsufflation to achieve lower intra-abdominal pressures. Addition of 10 cmH_2O of positive end-expiratory pressure (PEEP) has been shown to attenuate the effects of pneumoperitoneum in respiratory mechanics [81]. Conversion to an open procedure must be considered if complications persist. Helium may be used as an alternative insufflant, which may prevent respiratory acidosis and hypercapnia associated with CO_2 pneumoperitoneum. Gasless or apneumic laparoscopy can similarly be used as an alternative to avoid the potential side effects of CO_2 pneumoperitoneum. Despite these problems in patients with respiratory disease, laparoscopy remains preferable to laparotomy because of reduced postoperative respiratory dysfunction.

Renal patients

Renal function and renal blood flow are decreased during pneumoperitoneum. The magnitude of the decrease is dependent on factors such as preoperative renal function, level of hydration, duration of pneumoperitoneum, level of pneumoperitoneum, and patient positioning. Increased intra-abdominal pressure can reduce urine output. Assuming a euvolemic status, intraoperative management for oliguria should include evaluation of the Foley catheter for patency and laparoscopic examination of the bladder. Anuria may develop in patients with pre-existing renal dysfunction. The role of dopamine to enhance intraoperative urine output is unclear. Infusion of low doses of dopamine during laparoscopic colectomy had higher urine output compared with patients who did not receive dopamine [82]. Infusion of low-dose nicardipine during robot-assisted laparoscopic radical prostatectomy has also been shown to offset the effects of pneumoperitoneum and extreme head-down tilt on renal function [83]. As a corollary, a management strategy to avoid hypovolemia and preserve renal perfusion pressure has been shown to preserve renal function in both the donated and remaining kidneys during laparoscopic kidney donation [84]. It appears that excessive fluid administration is not necessary to preserve renal function, assuming the absence of hemorrhage and use of a low level of intra-abdominal pressure. A host of neurohormonal changes also occur, resulting in increases in aldosterone, renin, and antidiuretic hormone [85, 86]. These changes may be exaggerated in patients with pre-existing renal dysfunction, but they are not permanent [85]. Renal function and electrolytes return to baseline within a variable time after pneumoperitoneum is released [87, 88]. Although renal function and renal blood flow do not appear to be clinically deleterious, knowledge of the effects of insufflation is important to effectively monitor and maintain an appropriate fluid balance for patients during laparoscopy.

Pregnant patients

Laparoscopic surgery during pregnancy presents several concerns, including increased risk of miscarriage or premature labor, increased risk of damaging the gravid uterus, and significant fetal acidosis. Abdominal and pelvic procedures are associated with the greatest incidence of premature labor. Procedures are best scheduled in the mid trimester, decreasing the risk of teratogenic effects of some medications (first trimester) or preterm labor (third trimester). Laparoscopic surgery is considered safe during pregnancy, however [89]: laparoscopy carried out between 4 and 32 weeks of gestation have resulted in uncomplicated pregnancies [90–94]. On hemodynamics and breathing, when compared to non-pregnant patients, pneumoperitoneum does not induce any additional effect. CO_2 pneumoperitoneum nonetheless can cause significant fetal effects, including increased heart rate, increased arterial pressure, and increased blood pH [95]. Interestingly, fetal outcomes are similar with either laparotomy or laparoscopy [96]. For monitoring, preoperative and postoperative fetal heart rate and uterine activity must be assessed at a minimum. Fetal monitoring may be performed using transvaginal ultrasonography [90]. Capnography may be adequate to guide maternal ventilation. As long as physiologic maternal alkalosis is achieved, uteroplacental blood flow should be maintained. Essentially, fetal perfusion pressure and blood gas values should remain at normal levels [97]. Left uterine displacement should be used after 20 weeks of gestation and aspiration prophylaxis administered to all pregnant patients. Other technical considerations should include fetal shielding, pneumatic stockings, and open trocar placement [98].

Obese patients

Obesity is complex and multifactorial, and is defined as a condition of excessive fat accumulation in adipose tissue to the extent that health deteriorates and life-expectancy is shortened. Given the comorbidities associated with obesity, it is surprising to find a paucity of literature revealing a definitive increase in overall operative risk. The widespread introduction of laparoscopic gastric bypass has significantly augmented the experience with laparoscopy in morbidly obese patients. Laparoscopy has many advantages, including less postoperative pain, earlier recovery, and reduced risk of pulmonary complications.

Preoperative investigation should be directed by history and examination findings of the patient. Spirometry as a preassessment screening tool does not make any difference in predicting postoperative pulmonary complication [99]. A careful preoperative assessment of a patient's upper airway is always required because mask ventilation and tracheal intubation can be a challenge. Patients using nasal continuous positive airway pressure and bi-level-positive airway pressure should be instructed to bring them to the hospital to use in the PACU after surgery. A preoperative discussion about the need for extubation when fully awake and in a sitting position may minimize patient anxiety and improve cooperation during recovery.

Basic intraoperative monitoring should include $PetCO_2$, urine output, and $PaCO_2$ levels. Certain obese patients, particularly those with evidence of pulmonary hypertension and cor pulmonale, may benefit from invasive cardiovascular monitoring, including Swan–Ganz catheterization and radial arterial catheter with routine blood gas measurement.

Atelectasis can be a significant clinical problem in the perioperative period because functional residual capacity and pulmonary compliance are reduced in obese patients [100]. Concurrently, pneumoperitoneum worsens compliance and functional residual capacity, requiring modification of ventilatory parameters.

Endotracheal tube position must be carefully monitored because both the head-down position and abdominal insufflation can cause migration of the endotracheal tube into the right mainstem bronchus [101].

Hypoxemia during mechanical ventilation in obese patients, at least, is due in part to ventilation–perfusion mismatch [102]. PEEP has been shown to provide an improvement in ventilation–perfusion mismatching and arterial oxygenation in morbidly obese patients through alveolar recruitment [103], but adverse effects on cardiac output and oxygen delivery may offset these benefits. Patients with obstructive sleep apnea and obesity hypoventilation syndrome should be closely monitored and supplemental oxygen should be provided in the immediate postoperative period. The maximum decrease in PaO_2 usually occurs 2–3 days postoperatively. Depression of ventilation in obese patients is a concern. As part of a multimodal approach, opioids and adjuvant analgesics comprise an effective method for producing postoperative analgesia.

The likelihood of DVT and pulmonary embolism is also increased, emphasizing the importance of physiotherapy and the need for prophylactic anticoagulation. Since the risk of pressure ulcers and subsequent wound infection is high, meticulous attention to pressure points is essential. Rhabdomyolysis, potentially a fatal complication associated with prolonged surgery in obese patients, may be associated with gluteal muscle necrosis [104, 105]. As such, preventive measures should include meticulous intraoperative positioning, suitable intraoperative padding, and limiting the duration of the operation. Serial creatine phosphokinase (CPK) measurement is essential. Critical CPK level may be treated aggressively with hydration and diuresis to prevent renal failure.

Despite these potential pitfalls, laparoscopy is usually well tolerated in obese patients and many studies show reductions in overall morbidity when a laparoscopic technique is used [106, 107].

Postoperative pain

Laparoscopy has been shown to reduce postoperative pain and analgesic consumption [108]. Improving postoperative analgesia in laparoscopic surgery remains an area of continued interest.

The nature of pain includes visceral pain, parietal pain resulting from peritoneal inflammation and tissue manipulation at the trocar or hand-assist site, and shoulder-tip pain resulting from diaphragmatic irritation [108, 109]. The mainstay of pain prevention and treatment relies on local anesthesia, nonsteroidal anti-inflammatory drugs (NSAIDs), and opioids [110–112]. Dexamethasone is also an effective adjuvant in reducing postoperative pain [113]. Residual pneumoperitoneum gas has been shown to contribute to postoperative pain [111, 114]. Surgeons are encouraged to desufflate the pneumoperitoneum gas to the greatest extent possible at the conclusion of the procedure.

Multimodal analgesia is now recommended due to the multifactorial etiology of pain after laparoscopy. The pharmacologic underpinnings of this technique involve attacking pain signaling at different sites (Table 69.1). The goal is to reduce the total dose of any one medication by attending to patient analgesic requirements through various receptor modulations. Employing this technique minimizes the need for high doses of opioids and their accompanying toxicity. It may decrease the patient dependence on opioids for acute postoperative pain control.

Opioids are effective in treating pain after laparoscopic procedures, but these medications are not without adverse effects. Numerous side effects include nausea and vomiting, constipation, ileus, confusion, sedation, urinary retention, delirium, pruritus, headache, respiratory depression, and potentially more serious effects, including muscle rigidity and hypotension. Paradoxically, opioids can cause hyperalgesia [115–117].

Acetaminophen has been shown to decrease opioid requirements by 25–35% [118]. It has minimal effect on platelets and gastric mucosa, and does not trigger asthma in susceptible patients. Acetaminophen is hepatotoxic at dosages exceeding 4 g/day, so its use should be monitored in patients with liver disease and in patients receiving hepatotoxic medications.

NSAIDs are often administered as adjuvant during and after surgery. They have analgesic properties comparable with opioids, but do not have opioid-related side effects. There seems to be no significant differences among various NSAIDs in analgesic efficacy. Following surgery, patients treated with preoperative NSAIDs consume 25–33% fewer opioids and report lower pain scores [119]. Caution should be exercised, however, in prescribing NSAIDs to patients with pre-existing renal dysfunction [119, 120], asthma or nasal polyps, ulcers or gastrointestinal bleeding. NSAIDs may cause fluid retention in the elderly and may be associated with impaired bone healing in orthopedic surgical patients [121].

The gabapentinoid group of drugs, gabapentin and pregabalin, have recently gained favor in the treatment of acute postoperative pain. They have been shown to decrease pain, opioid consumption, and opioid-related side effects postoperatively [122, 123]. A randomized, placebo-controlled, double-blind study in healthy volunteers showed that gabapentin enhanced the analgesic effect of morphine [124]. These adjuvant agents have potential, but more work is required to determine the optimal dosing and duration of use.

NMDA receptor antagonists are a mainstay in the treatment of opioid-tolerant and hyperalgesic patients.

Table 69.1 Commonly used analgesics for laparoscopic surgery.

Analgesics	Sites of action
Opioids	Peripheral: reduced calcium entry into nociceptive afferents Spinal cord: hyperpolarization of dorsal horn neurons Supraspinal: enhanced efferent inhibitory neuron activity
Acetaminophen	Peripheral: suppresses peripheral PGE2 release and interleukin formation CNS: binds cannabinoid-1 receptor
NSAIDs	COX inhibition with decreased PGE2 centrally and peripherally
Gabapentinoids	Brainstem: enhanced descending inhibitory pathways Spinal and afferent peripheral nerves: α2 subunits of calcium channels
Ketamine	Inhibits glutamate binding of NMDA receptors in dorsal horn of spinal cord
Dexmedetomidine, clonidine	Supraspinal: α2 adrenoreceptors in locus ceruleus Spinal: α2 adrenoreceptors in the dorsal horn
Glucocorticoids	Decreases central and peripheral inflammatory mediators
Local anesthetics	Peripheral: decreased interleukin release Central: inhibition of dorsal root ganglion and frequency-dependent conduction

PGE2, prostaglandin E2; NSAID, nonsteroidal anti-inflammatory drug; COX, cyclo-oxygenase; CNS, central nervous system.

Ketamine, the prototypical NMDA receptor antagonist, has undergone a dramatic renaissance in clinical use. Subanesthetic dosages of 10–15 mg given just before surgical incision seem to diminish pain for several days and are not associated with the significant adverse effects related to ketamine administration [125,126]. A Cochrane Review concluded that subanesthetic ketamine dosing effectively reduces morphine requirements in the first 24 h after surgery, as well as PONV [127].

The alpha2-adrenergic agonists, clonidine and dexmedetomidine (DEX), have significant anesthetic and analgesic-sparing effects. Intravenous perioperative DEX infusion during abdominal surgery has been shown to provide postoperative analgesia and reduce postoperative morphine requirements without clinically relevant bradycardia or hypotension, oversedation, or respiratory depression [128–130]. In a study involving morbidly obese patients, DEX infusion (0.5–0.7 μg/kg/h), instituted 1 h before the end of surgery and continued in the PACU stay, was associated with lower opioid requirements, better pain control, and was not associated with respiratory depression [131].

Glucocorticoids act on diverse targets to control inflammatory, metabolic, hormonal, and immune responses to surgery. The benefits of corticosteroids may be maximized by repeated dosages. The fear of adverse effects (such as adrenal suppression, wound healing, or gastrointestinal ulceration) likely hinders their widespread clinical use, despite modest analgesic actions [113].

Local anesthetics have a variety of applications in perioperative pain management. Local anesthetic infiltration (e.g. intraperitoneal, port-site infiltration) for postoperative pain relief after laparoscopic surgery produces mixed results [132–137]. Although there was some initial enthusiasm that protracted analgesia would result from surgical-site local anesthetic infiltration, the preponderance of evidence does not support this concept.

In summary, postoperative pain remains a major reason for delayed discharge, unplanned admission, and patient dissatisfaction. The management of acute postoperative pain is complex. Recent advances in our understanding have improved our approach to postoperative pain management, but there is a paucity of randomized clinical trial data to provide definitive, high-quality, evidence-based recommendations. Selected nonopioid analgesics can be used as part of a multimodal approach for optimizing acute pain management. Further studies are needed, however, to determine the optimal dosing and duration of use, as well as the patient population that would benefit from these adjuvant analgesics. The use of the multimodal approach to analgesia will continue to advance, further improving patients' long-term outcomes and levels of satisfaction.

Postoperative nausea and vomiting

Despite widespread use of antiemetics for preventing and treating PONV, many surgical patients who undergo general anesthesia still experience PONV in the PACU, the hospital, and at home after discharge [138, 139]. PONV can increase medical costs from delayed recovery room discharge or unplanned admissions after outpatient surgery [140]. Additionally, nausea and vomiting are among the most unpleasant experiences associated with surgery for many patients and one of the most common reasons for poor patient satisfaction in the postoperative period [141]. PONV may be associated with wound dehiscence, pulmonary aspiration, electrolyte disturbance, dehydration, Mallory–Weiss tear, loss of vision, and subcutaneous emphysema [142–144].

The etiology of PONV is multifactorial. Patient-related risk factors for PONV include female gender, nonsmoking status, anxiety, age 3–14 years, history of PONV, and motion sickness or migraines [144–149]. Surgery-related factors include increasing duration of surgery [149, 150] and certain types of surgery, although causality has not been clearly established (with the exception of strabismus surgery in children) [146]. Anesthesia-related factors include use of volatile agents [150], nitrous oxide [151, 152], opioids [145, 153], and large doses of neostigmine [154] for reversal of neuromuscular blockade.

Simplified scoring systems developed by Apfel *et al.* [145] and Eberhart *et al.* [155] to identify patients at risk for PONV have been shown to significantly reduce the overall incidence of PONV. The Apfel score, which was developed for adults, consists of four predictors: female gender, history of motion sickness or PONV, nonsmoking status, and the use of opioids for postoperative analgesia. The Eberhart score, which was developed for children, similarly consists of four predictors: duration of surgery of 30 min or longer, age 3 years or older, strabismus surgery, and history of POV in the child or POV/PONV in a parent or sibling.

The pathogenesis of PONV involves several receptor systems, including dopaminergic D2 receptors, cholinergic muscarinic receptors, histaminergic H1 receptors, serotonin 5-HT3 receptors, and NK1 receptors. Antagonists to these receptors are the mainstay of PONV management.

The most commonly used dopamine receptor antagonists are metoclopramide and droperidol. Droperidol at a dose of 0.625–1.25 mg has been demonstrated to be highly effective for the prophylaxis of PONV [156]. Concerns regarding prolongation of QTc interval led to the issuance of a black box warning by the US Food and Drug Administration (FDA) in December 2001. It appears, however, that QTc prolongation is dose dependent. When given at doses less than 2.5 mg, this prolongation is modest and transient [157]. The use of this antiemetic continues to decline. Haloperidol at a dose of 1–2 mg may be a suitable alternative, but data regarding safety and efficacy are lacking [158, 159]. Metoclopramide in doses of 25 mg and 50 mg was similarly effective for PONV prophylaxis [160]. The commonly used dose of 10 mg seems to be no more effective than placebo [161, 162]. Promethazine is also an effective antiemetic [163], but its use is limited by sedation and prolonged recovery from anesthesia [162]. Promethazine also has a black box warning regarding the risk of respiratory depression in children younger than 2 years [164].

The most widely used anticholinergic for PONV prophylaxis is transdermal scopolamine (TDS). It is effective in the setting of outpatient laparoscopy [165]. Common side effects, including dry mouth, visual disturbances, dizziness, and agitation, limit its use, however [166]. Antihistamines, including diphenhydramine and dimenhydrinate, seem to be similarly effective for PONV prophylaxis, but their use is limited due to side effects such as sedation, dry mouth, blurred vision, urinary retention, and delayed recovery room discharge [167].

Serotonin receptor antagonists are highly specific and selective for nausea and vomiting. First-generation 5-HT3 receptor antagonists include ondansetron, granisetron, dolasetron, and tropisetron. New-generation 5-HT3 receptor antagonists approved by the FDA include palonosetron. There seems to be no evidence that there is any difference in efficacy and side effect profile among the various 5-HT3 receptor antagonists, but first-generation 5-HT3 receptor antagonists are extensively metabolized. As a result, ultrarapid metabolizers have an increased incidence of therapeutic failures [167–169].

Palonosetron, on the other hand, has a 30-fold greater binding affinity [170] for the receptor than other antagonists and a substantially longer half-life [171]. These unique characteristics may confer advantages when used in the treatment of established PONV, but further investigations are needed.

Aprepitant is the only NK1 receptor antagonist currently available for management of PONV in the USA [1]. It has a long duration of action and a favorable side effect profile. It seems to be effective for prophylaxis against vomiting.

Other antiemetic interventions include dexamethasone [151], which is most effective when given at induction of anesthesia [172], total intravenous anesthesia with propofol [173], and aggressive intravenous hydration [174]. Other strategies to keep the baseline risk of PONV low are avoidance of emetogenic stimuli (nitrous oxide [175], inhalational agents [176], minimal use of intraoperative and postoperative opioids, judicious use of neostigmine [154], and nonpharmacologic techniques, e.g. acupuncture [177]).

Due to the multifactorial etiology of PONV, a panel of experts recommends a multimodal approach to managing patients at moderate-to-high risk for PONV [24] and, according to the issued guideline, a risk-adapted strategy should be adopted for PONV prophylaxis. Strategies to reduce baseline risk for PONV should also be employed. For the treatment of established PONV, an agent from a pharmacologic class different from the agent used for prophylaxis should be used. If no prophylaxis was used, administration with a low-dose 5-HT3 receptor antagonist is recommended.

In summary, improved understanding of the risk factors for PONV and effective patient communication may help establish the level of risk, determine the need for preventive measures, and implement rescue treatment immediately by targeting mechanisms that have not been tried before.

Conclusions

General endotracheal anesthesia is the best choice for most cases of laparoscopic and robotic urologic surgery. In specific circumstances, alternatives such as the use of a laryngeal mask airway, regional anesthesia, and local anesthesia can be considered. The choice of anesthesia and monitoring are mostly dependent on expected surgical challenges and patient comorbidities. Both the surgeon and the anesthesiologist need to be aware of the physiologic effects of laparoscopy when selecting patients for this form of surgery. Most patients tolerate anesthesia for laparoscopic surgery safely but an occasional patient will be challenged by the cardiac and pulmonary effects of positioning and insufflation. These issues need to be discussed prior to the induction of anesthesia. To aid in the communication between surgeon, anesthesiologist, and operating room nurse, many health care institutions have adopted the World Health Organization (WHO) surgical safety checklist, which has built-in communication protocols, prior to induction of anesthesia, prior to incision, and during closure of surgery. In a multinational study by Gawande *et al*., the use of the WHO surgical safety checklist reduced postoperative morbidity and mortality by 36% [178].

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CHAPTER 70

Pneumoperitoneum: Physiologic Effects

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Introduction

In its infancy, laparoscopy was largely employed as a diagnostic tool with limited therapeutic applications such as tubal ablation [1]. As such, these procedures were typically short in duration, associated with minimal morbidity, and most commonly performed in healthy, young females. With the introduction of the laparoscopic cholecystectomy in 1990 and nephrectomy in 1991, the removal of larger solid organs became feasible and laparoscopy evolved from the realm of diagnostic to therapeutic procedures [2, 3]. Since that time, the skill and instrumentation of the laparoscopic surgeon has significantly expanded, which in turn has increased the complexity and duration of these procedures. Modern day laparoscopic and robotic surgeries address a broad spectrum of pathologic conditions in patients with varied states of health. As a consequence, the impact of prolonged pneumoperitoneum has become a central issue for these patients both during and following surgical procedures. This chapter addresses the physiologic effects of pneumoperitoneum and the potential complications arising from it.

Insufflation agents

Early in the evolution of laparoscopy, pneumoperitoneum was established using either room air or oxygen [4]. However, the potential for significant adverse sequelae relating to venous air embolism, intra-abdominal explosion, and combustion with oxygen and room air soon terminated their roles in a clinical setting. The consensus among laparoscopic surgeons was that the ideal insufflation agent should be readily available, inexpensive, noncombustible in nature, and rapidly soluble in plasma [5]. With such criteria, the most commonly employed gas for insufflation is CO_2. The rapid absorption of CO_2 minimizes the likelihood of postoperative abdominal distention and directly contributes to the low probability of developing an air embolus. Nonetheless, its favorable absorption characteristics can precipitate a series of more significant physiologic sequelae, including hypercapnia, hypercarbia, or cardiac dyssrythmias. Such considerations are typically self-limiting, except for patients with depressed cardiopulmonary function or those with chronic obstructive pulmonary disease (COPD). These latter patients in particular may be unable to increase minute ventilation sufficiently to adequately compensate for increased CO_2 absorption.

Alternative insufflation agents have included NO_2 and helium. In the 1970s and 1980s, NO_2 emerged as a favorite insufflation agent with cited benefits including lower cost, less peritoneal irritation, and fewer cardiovascular adverse effects when compared to CO_2 [6, 7]. However, unlike CO_2, NO_2fails to suppress combustion and case reports of intraoperative explosion have limited its therapeutic use [8, 9]. As such, NO_2 can only be used during laparoscopic procedures that do not require the use of electrosurgical equipment. Helium, in contrast, is an inert and noncombustible insufflant, with several studies in animal models demonstrating favorable effects on arterial partial pressure without evidence of

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hypercarbia or acidosis [10]. Clinical experience has further supported the use of helium in select patients with pulmonary disease in whom hypercarbia would be poorly tolaterated [11]. The principal drawback of helium is its lower blood solubility, which may be associated with a higher risk of gas embolism.

The focus of this chapter will be on sequelae of pneumoperitoneum, specifically as they relate to CO_2 insufflation, because this is the most commonly used agent during laparoscopic procedures. Generally speaking, physiologic effects of pneumoperitoneum are attributable to two independent variables: (1) increased intra-abdominal pressure; and (2) absorption of the gaseous medium used for insufflation.

Pressure-related effects

Cardiovascular effects

The cardiovascular impact of increased intra-abdominal pressure relates to changes in cardiac function and venous return (Table 70.1). Animal studies suggest that elevated intra-abdominal pressure contributes to an increase in peripheral vascular resistance, which negatively influences cardiac function (12–14). The effect of increased intra-abdominal pressure on venous return is determined by changes in venous resistance and mean systemic pressure. At low right atrial pressures, increased intra-abdominal pressure causes compression of the inferior vena cava (IVC), which inhibits venous return. In contrast, at high right atrial pressures, the IVC resists compression and venous return is augmented by increased intra-abdominal pressure [12–15]. Additionally, increased intra-abdominal pressure mediates compression of small capacitance vessels, thereby augmenting venous return and increasing mean systemic presssure.

Table 70.1 Cardiovascular and renal effects of increased intra-abdominal pressure (10–20 mmHg).

Parameter	Change
Cardiovascular	
Heart rate	↔ or ↑
Mean arterial pressure	↑
Systemic vascular resistance	↑
Venous return	↓
Central venous pressure	↑
Cardiac output/index	↔ or ↓
Stroke volume	↓
Renal	
Renal blood flow	↓
Glomerular filtration rate	↓
Urine output	↓
Serum creatinine	↔ or ↑
Vasopressin (ADH)	↑

Clinically, the degree to which various cardiovascular parameters change during surgery relates to several factors, including intra-abdominal pressure, patient position, CO_2 absorption, intravascular volume status, pre-existing cardiopulmonary status, and current medications. Pneumoperitoneum appears to uniformly induce phasic hemodynamic changes that are initially characterized by a decrease in cardiac index by approximately 50% within 5 min of insufflation, followed by a gradual increase in cardiac index as systemic vascular resistance (SVR) drops after 10 min of insufflation [16]. McLaughlin *et al*. demonstrated that an intra-abdominal pressure of 15 mmHg resulted in a 30% decrease in cardiac output and stroke volume, and a 60% increase in mean arterial pressure (MAP) [17]. Dexter *et al*. further randomized 20 laparoscopic cholecystectomy patients to either low (7 mmHg) or high (15 mmHg) pressure pneumoperitoneum. Although heart rate and MAP increased to a similar degree in both groups, stroke volume and cardiac output were depressed to a greater extent in the 15 mmHg group [18].

Changes in patient position can also alter hemodynamic function. In particular, patients are often placed in a Trendelenberg or reverse Trendelenberg position to facilitate visualization during laparoscopy. Joris *et al*. highlighted such changes by measuring hemodynamic changes in patients undergoing laparoscopic cholecystectomy [19]. They observed that the reverse Trendelenberg position ("head up") reduced the MAP by 17% and cardiac index by 14% when compared to the neutral horizontal position. Furthermore, the combined effect of insufflation and reverse Trendelenberg position was a reduction in cardiac index with an unchanged MAP. Despite these measureable changes, the European Association for Endoscopic Surgery practice guidelines concensus concluded that at intra-abdominal pressures up to 15 mmHg, the decrease in venous return and cardiac output is minimal and without consequence for healthy patients [20]. At this pressure, adequate volume loading mitigates the cardiovascular effects of the pneumoperitoneum, which are most pronounced during its induction [21].

Special consideration, however, is necessary for patients with limited cardiac reserve. In such patients, increases in heart rate and afterload coupled with an elevated SVR can potentially increase venticular wall tension, which may precipitate myocardial ischemia. When investigating the effects of laparoscopy on patients with severe heart disease [American Society of Anesthesiologits (ASA) class III or IV], Safran *et al*. noted significant elevations in SVR and MAP with a reduction in cardiac output at insufflation pressures of 15 mmHg [22]. These authors concluded that in patients with significant pre-existing heart disease, insufflation causes a transient cardiac decompensation due to inadequate left ventricular reserve. Thus, for patients with limited cardiac reserve, the increased work necessary to maintain adequate circulation necessitates careful attention to the intra-abdominal pressure, volume status, and blood pressure to avoid potentially deleterious cardiovascular changes [20, 23].

Renal effects

Elevated intra-abdominal pressure also affects renal hemodynamics (Table 70.1). As early as 1923, Thorington and Schmidt noted in a bovine model that intra-abdominal pressures of greater than 15 mmHg and greater than 30 mmHg were associated with oliguria and anuria, respectively [24]. Similarly, in a study of 17 normal human volunteers, Bradley and Bradley observed a decrease in urine output after pressurizing a pneumatic abdominal girdle to 80 mmHg, which corresponds to an average intra-abdominal pressure of 20 mmHg. They observed that IVC pressure rose from 5.8 to 18.3 mmHg, with an associated reduction in effective renal plasma flow and glomerular filtration rate (GFR) [25].

Several mechanisms have been proposed to account for the renal dysfunction associated with increased intra-abdominal pressures. Thorington and Schmidt hypothesized that increased renal vein pressure is the etiology underlying renal functional changes [24]. Others speculated that direct renal compression accounts for the changes in renal blood flow (RBF) and functional impairment. Finally, changes in antidiuretic hormone (ADH, vasopressin) have been implicated as a cause of oliguria in patients with increased intra-abdominal pressure. However, decreased cardiac output, ureteral compression, and renal ischemia do not appear to contribute to laparoscopy-associated oliguria (21, 26–28).

Clinical experience with elevated intra-abdominal pressure secondary to bleeding or edema parallels that seen during laparoscopy. Richards *et al.* noted oliguria or anuria postoperatively in four patients who subsequently required re-exploration for bleeding associated with abdominal distention. In all four cases urine output remained low despite vigorous fluid resuscitation and normal-to-high arterial and central venous pressures. Operative decompression resulted in a prompt diuresis in each case [29]. Similarly, Fietsam *et al*. described an "intra-abdominal compartment syndrome" in four patients with massive retroperitoneal interstitial edema following abdominal aortic aneurysm repair who developed severe oliguria despite elevated central venous pressures [30]. With decompressive laparotomy, urine output increased significantly.

Animal models have implicated different possible etiologies underlying decreased RBF observed during laparoscopy. Harman *et al*. favored direct renal compression as the cause for decreased RBF and GFR in an experimental model of seven anesthetized dogs [21]. In this study, inflation of an intraperitoneal bag with air to a pressure of 20 mmHg resulted in a 22% reduction in GFR; at 40 mmHg, three dogs became anuric and the GFR in the remaining four dogs dropped to 7% of baseline. Likewise, RBF decreased from a baseline of 160 mL/min at 0 mmHg pressure to 36 and 9 mL/min at 20 and 40 mmHg intra-abdominal pressure, respectively. Furthermore, intravascular volume expansion had no effect on GFR or RBF. IVC and renal vein pressure correlated with intra-abdominal pressure, while renal artery pressure was relatively unaffected by variations in intra-abdominal pressure. With elevated intra-abdominal pressure, the increase in renal vascular resistance far exceeded the increase in systemic vascular resistance. These findings suggest that direct effects on the kidney, rather than changes in systemic hemodynamics, are responsible for the renal dysfunction seen with increased intra-abdominal pressure.

Other animal studies have implicated that increased intra-abdominal pressure during laparoscopy impacts renal hemodynamics. Chiu *et al*. measured the RBF in six pigs undergoing insufflation at varying levels of intra-abdominal pressure [31]. Using air as the insufflant, intra-abdominal pressure was gradually increased from 0 to 40 mmHg. Measurements of carotid artery blood flow (CABF) (representing cardiac output), carotid artery blood pressure (CABP), IVC pressure (IVCP) as a surrogate for intra-abdominal pressure, and RBF were recorded at various intra-abdominal pressures. Although CABP remained constant with increasing intra-abdominal pressure, CABF decreased linearly. Interestingly, renal cortical blood flow (RCBF) decreased exponentially with increasing intra-abdominal pressure. In contrast, renal medullary blood flow increased up to an intra-abdominal pressure of 20 mmHg and then dropped steadily as intra-abdominal pressure reached 40 mmHg. Moreover, the decrease in RCBF could not be accounted for solely by decreased cardiac output. Specifically, CABF decreased linearly with rising intra-abdominal pressure, whereas RCBF decreased exponentially. McDougall *et al*. utilized noninvasive magnetic resonance imaging (MRI) to similarly evaluate renal vessel blood flow [27]. These authors similarly demonstrated reduced cardiac output, reduced flow velocity in the renal vessels, decreased renal parenchymal perfusion, and reduced renal cortical and medullary blood flow associated with abdominal insufflation. Of note, while the exact mechanism by which RBP is impacted by pneumoperitoneum is not fully elucidated, the effects appear to be influenced by volume status. London *et al.*

noted that when subjected to an intra-abdominal insufflation pressure of 15 mmHg, pigs receiving only maintenance fluids had a 30% reduction in RBP, while those hydrated more aggressively had improved preservation of this parameter [32].

McDougall *et al.* further demonstrated in a porcine model that decreased renal vein blood flow is invariably associated with oliguria during laparoscopy [33]. At intra-abdominal pressures of 10 mmHg or greater, urine output, creatinine clearance, and renal vein flow decreased significantly despite minimal change in cardiac output. These effects were not gas specific; similar findings were observed with CO_2 or argon as an insufflant. Administration of renal doses of dopamine (2 μg/kg/min) and the use of ureteral catheters failed to overcome the effects of elevated intra-abdominal pressure. ADH was also measured, and no significant change was observed in any group despite increasing intra-abdominal pressure. Of note, 2 h after desufflation, ADH fell by 50% in all groups. Overall, these data suggest that impaired renal vein flow may be one mechanism accounting for the observed decrease in urine output.

During the early 1990s, a number of reports highlighted that patients undergoing lengthy laparoscopic procedures had significant intraoperative oliguria that resolved after desufflation [34, 35]. This is now a well-known clinical phenomenon. The role of ADH in promoting this oliguria is unclear. While there is a clear component of vascular and renal parenchymal compression, there is also evidence of increased ADH levels with pneumoperitoneum [36–38]. These studies have postulated that insufflation results in reduced preload, which contributes to lower right atrial volume and pressures. This in turn mediates release of vasopressin, which then acts on the distal tubule and collecting ducts to promote reabsorption of water. Rat models have noted that blocking the effects of vasopressin via a receptor antagonist can partially reverse the oliguria during insufflation [39].

In summary, the cause of decreased renal function observed during pneumoperitoneum is likely multifactorial.

Nonrenal visceral effects

Changes in blood flow observed with elevated intra-abdominal pressure are not limited to the kidney. Gastric mucosal perfusion can be assessed by gastric intramucosal pH and serves as a surrogate marker for splanchnic perfusion. Several groups have noted decreases in pH (and thus splanchnic flow) both during pneumoperitoneum as well as into the postoperative period. [16, 40]. Caldwell and Ricotta assessed blood flow to a number of visceral organs in dogs subjected to varying intra-abdominal pressures with an intraperitoneal inflatable bag [41]. Visceral blood flow decreased in all organs (stomach, small bowel, pancreas, colon, liver, spleen, and kidney) out of proportion to the decrease in cardiac output, with the exception of the adrenal gland. Similarly, Hashikura *et al.* measured blood flow to the liver and kidney in seven pigs subjected to intra-abdominal pressures of 6, 12, 18, and 24 mmHg during CO_2 insufflation [42]. At higher pressures, blood flow to the liver was significantly decreased. Since splanchnic ischemia is a known risk factor for bacterial translocation across the gut wall, it is not suprising that experimentally pneumoperitoneum has been associated with increased bacterial translocation from the peritoneum into the blood [43]. This phenomenon, however, has not been recognized as a clinical cause of laparoscopic morbidity.

Intracranial pressure

Laparoscopy has a well-documented impact on intracranial pressure (ICP). Both experimental [44–48] and clinical [49] studies have demonstrated an increase in ICP associated with CO_2 pneumoperitoneum. Although two clinical studies showed a direct correlation between ICP and PCO_2 [50, 51], Josephs *et al.* found in an animal model that the rise in ICP was independent of changes in arterial PCO_2, PO_2, pH, or MAP [44]. The Trendelenberg position appears to worsen the increase in ICP associated with insufflation, although the supine or reverse Trendelenberg position does not eliminate the observed increase [48]. Furthermore, Schob *et al.* observed that the rise in ICP with pneumoperitoneum also occurred with other insufflation agents (NO_2 and helium), although to a lesser degree than with CO_2 [52].

Several theories have been proposed to account for the rise in ICP observed during laparoscopy. One hypothesis incorporates the modified Monroe–Kellie doctrine, by which a change in one intracranial compartment [among four compartments: vascular, cerebrospinal fluid (CSF), osseous, and parenchymal] results in a compensatory change in the other nonosseous compartments. Rapid changes in one compartment, however, may preclude compensation, resulting in a rising ICP. Este-McDonald *et al.* postulated that abdominal insufflation can increase intrathoracic pressure, leading to obstruction of venous outflow from the spinal cord via the lumbar and pelvic plexuses [46]. The increased volume of the vascular intracranial compartment induces a rise in ICP. Others have theorized that impaired absorption of CSF accounts for the increase in ICP. This theory is further supported by the finding of impaired CSF absorption in anesthetized pigs in whom radioactive iodinated human serum albumin (RISA) was injected into the CSF. A reduced rate of CSF absorption (by 55%) was demonstrated by measuring RISA in the

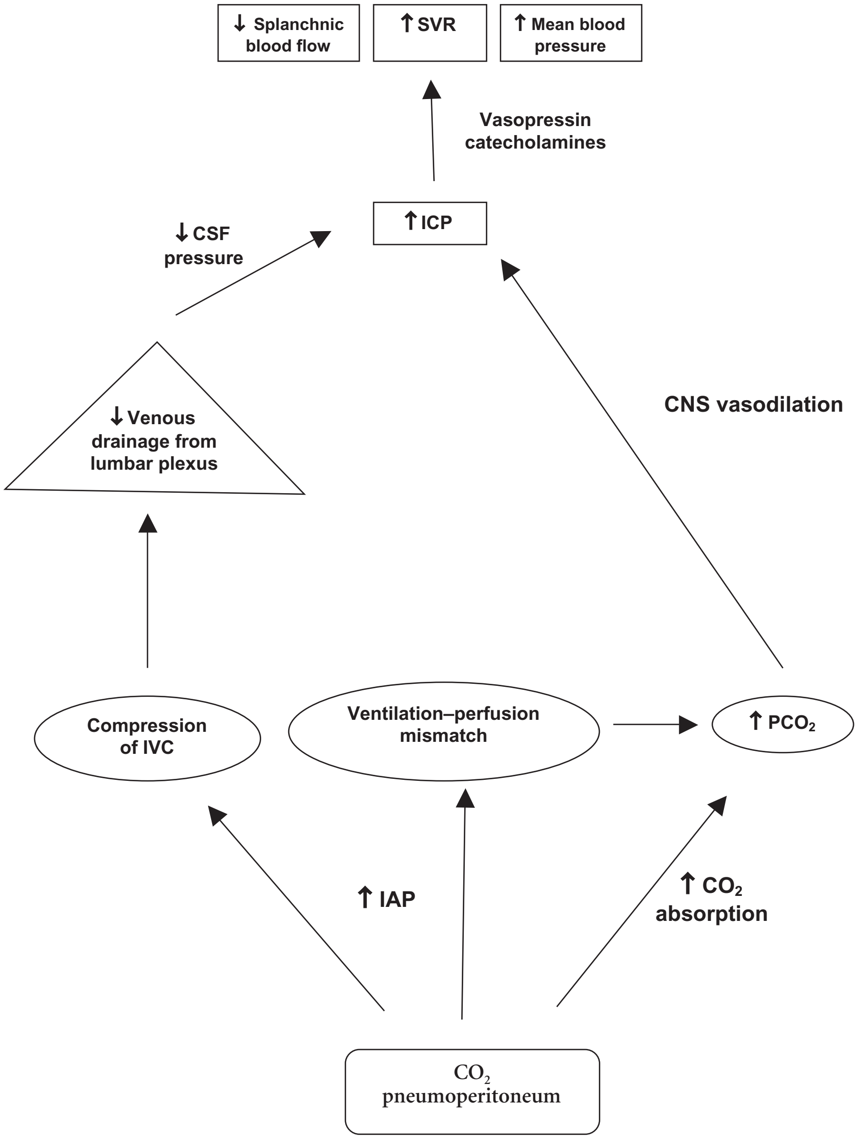
↓ Splanchnic blood flow
↑ SVR
↑ Mean blood pressure
Vasopressin catecholamines
↑ ICP
↓ CSF pressure
↓ Venous drainage from lumbar plexus
CNS vasodilation
Compression of IVC
Ventilation–perfusion mismatch
↑ PCO_2
↑ IAP
↑ CO_2 absorption
CO_2 pneumoperitoneum

Figure 70.1 Model proposed by Rosenthal *et al.* to account for increased intracranial pressure and subsequent hemodynamic effects associated with CO_2 pneumoperitoneum. IAP, intra-abdominal pressure; IVC, inferior vena cava; CVP, central venous pressure; CNS, central nervous system; ICP, intracranial pressure; SVR, systemic vascular resistance.

blood over a 4-h period during CO_2 pneumoperitoneum to 15 mmHg pressure [53].

Conversely, Rosenthal *et al*. have postulated that the rise in ICP is mediated by a two-phase mechanism: (1) early, passive, venous effect, and (2) late, active, arterial effect (Figure 70.1) [45, 54]. In the early, mechanical stage, increased intra-abdominal pressure results in compression of the IVC with a resultant increase in CVP. This in turn impairs venous drainage from the lumbar plexus, thereby raising ICP. In the late stage, hypercarbia, due to ventilation–perfusion mismatch and peritoneal absorption of CO_2, causes vasodilatation of the intracranial vessels and a rise in ICP. Furthermore, acute elevation in ICP elicits a central nervous system response (Cushing reflex) mediated by release of catecholamines and vasopressin. The Cushing's reflex yields an increased MAP and SVR, while reducing splanchnic and visceral blood flow to ameliorate central venous return. Collectively, this array of hemodynamic changes may be accounted for by the rise in ICP.

The clinical significance of these observations in patients without pre-existing intracranial disease is unknown, although to date no cases of significant neurologic impairment directly attributable to pneumoperitoneum have been reported. However, for patients with a head injury or an intracranial lesion, the potential for increased ICP during CO_2 pneumoperitoneum could be dangerous. As such, laparoscopy may be

Table 70.2 Respiratory effects of increased intra-abdominal pressure (10–20 mmHg).

Respiratory parameter	Change
Peak inspiratory pressure	↑
Chest wall mechanical resistance	↑
Pulmonary compliance	↓
Alveolar dead space	↔ or ↑
Functional reserve capacity	↓
Forced vital capacity	↓
FEV_1	↓
Peak expiratory flow	↓

contraindicated in these patients or should be undertaken only under conditions of low intra-abdominal pressure or by gasless laparoscopy to avoid potentially dangerous elevations in ICP. Additionally, the use of intraoperative ICP monitoring in this situation is prudent [45, 46, 48].

Respiratory effects

Alterations in respiratory mechanics have also been noted with abdominal insufflation (Table 70.2). Specifically, increased intra-abdominal pressure impedes diaphragmatic excursion, contributing to decreased functional residual capacity and an increase in pulmonary dead space. As such, studies have documented that as airway pressures increase, pulmonary compliance (by nearly 50%) and functional reserve capacity decrease [16, 55, 56]. Motew *et al.* noted that the average peak airway pressure required to maintain a constant tidal volume in 10 women undergoing laparoscopy increased from 17.9 mmHg at 0 mmHg intra-abdominal pressure to 25.9 mmHg at 20 mmHg intra-abdominal pressure [57]. Such factors can contribute to hypoxemia if patients are allowed to breathe spontaneously during laparoscopic surgery. Controlled ventilation with adequate tidal volumes and incorporation of positive end-expiratory pressure (PEEP) can minimize alveolar atelectasis, thereby obviating ventilation–perfusion mismatch which contributes to hypoxemia [58]. Despite the considerations discussed above, the deleterious impact of pneumoperitoneum on intraoperative pulmonary mechanics is usually not clinically significant in healthy patients under general anesthesia [59]. However, in obese patients or those with lung disease, these perioperative changes can have deleterious effects, placing them at higher risk of pulmonary complications.

Finally, several studies have emphasized that postoperative pulmonary status following laparoscopy is favorable compared to an open surgical approach. Schwenk *et al.* reported on 60 patients who underwent laparoscopic (n = 30) or conventional (n = 30) resection of colorectal tumors and compared intraoperative respiratory mechanics [60]. These authors noted better forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), peak expiratory flow, and oxygen saturation of blood in the laparoscopic group compared to the open cohort. Similar observations were made by Hasukic *et al.* in a surgical population comprised of open and laparoscopic cholecystectomy series [61].

Effects from absorption of CO_2

CO_2 homeostasis

Independent of the mechanical effect of increased intra-abdominal pressure, pneumoperitoneum can alter hemodynamic and respiratory parameters secondary to absorption of CO_2. To understand the potential impact of infusing CO_2 under pressure into the abdomen, a review of basic CO_2 homeostasis is requisite.

CO_2 is the predominant by-product of cellular metabolism. As such, an efficient mechanism for its elimination is required. The carbonic acid–bicarbonate system provides means for CO_2 removal, while buffering against marked changes in arterial pH. Both components of the system can be regulated: bicarbonate in the kidney and CO_2 in the lungs. CO_2 generated in tissues diffuses into capillaries. Less than 10% of this CO_2 dissolves in the blood and is transported to the lungs. The majority of the CO_2 (about 70%), however, combines with water in red blood cells to form carbonic acid in a reaction catalyzed by carbonic anhydrase. Almost as rapidly as it is formed, carbonic acid dissociates into hydrogen iond (which complex with hemoglobin) and bicarbonate ions (which diffuse into the plasma):

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO^-{}_3$$

The remaining minor fraction of CO_2 complexes with hemoglobin and plasma proteins for delivery to the lungs [62]. The carbonic acid–bicarbonate system therefore provides a powerful buffering system: the elimination of CO_2 drives the reaction to the left, thereby reducing the number of hydrogen ions and increasing pH. In addition, increases in CO_2 or hydrogen ion concentration directly stimulate the chemosensitive area of the medulla, leading to respiratory stimulation and consequently to increased excretion of CO_2 [62].

Irrespective of whether or not CO_2 is produced as a by-product of tissue metabolism or is instilled into the peritoneum for laparoscopy, it is absorbed into the blood and ultimately equilibrates in the lungs. The movement of gas from one body compartment to another is controlled by the process of diffusion, which generally occurs from an area of high concentration to an area of low concentration. The rate at which a dissolved gas in liquid crosses an interface is determined by a number of factors, including the pressure differential across the interface, the solubility of the gas in the liquid, the distance the gas must traverse, the cross-sectional area of the fluid, the molecular weight of the gas, and the temperature of the gas and fluid. The *diffusion coefficient* defines the rate of diffusion of a specific gas for a given pressure differential and diffusion distance, thereby encompassing the solubility and molecular weight of the given gas. The diffusion coefficient is a relative number based on the diffusion coefficient of oxygen. The diffusion coefficients for several important respiratory gases are: O_2 1.00, CO_2 20.30, CO 0.81, N 0.53, and He 0.95. Clearly, CO_2 is more readily diffusible in body tissues than any of the other respiratory gases. This fact is central to choosing CO_2 as an ideal insufflant for laparoscopy. With establishment of a CO_2 pneumoperitoneum, the CO_2 partially dissolves in the peritoneal fluid and subsequently reaches equilibrium with the tissues and blood as determined by the diffusion coefficient.

Physiologic consequences of CO_2 absorption

The hemodynamic sequelae of hypercarbia have been characterized by Price into direct and indirect effects [63] (Table 70.3). Experimentally, lower pH (whether due to hypercarbia or otherwise) is associated with myocardial depression, resulting in decreased heart rate and force of contraction. Additionally, vasculature responds to a low pH by vasodilating. In contrast, CO_2 directly enhances sympathetic activity, which promotes cardiac contraction and induces peripheral vasoconstriction. Cardiac output and myocardial oxygen consumption increase in response to hypercarbia and may reflect increased sympathetic activity. Peripherally, increases in MAP are modest and suggest that local peripheral vasodilatory effects outweigh the central sympathomimetic effects. Clinically, Cullen and Eger evaluated the circulatory response to increased inhaled CO_2 in 42 healthy volunteers [64]. Like Price, they found increases in heart rate, stroke index, myocardial contractility, and peripheral blood flow; in contrast, total peripheral resistance dropped significantly.

Table 70.3 Hemodynamic effects of hypercarbia.

	Experimental effect		
Hemodynamic parameter	Direct effect*	Indirect effect⁺	Clinical effect
Heart rate	↓	↑	↑
Cardiac contractility	↓	↑	↑ CO
Vascular resistance	↓	↑	↓ SVR
Mean arterial pressure	No data	↑	Slight ↑ BP

*Direct local effect of hypercarbia
⁺Indirect effect of hypercarbia secondary to sympathetic stimulation.
CO, cardiac output; SVR, systemic vascular resistance; BP, blood pressure.

CO_2 pneumoperitoneum has been implicated in hemodynamic and respiratory alterations observed during laparoscopy. Early investigators observed that patients allowed to breathe spontaneously during laparoscopy began to hyperventilate [65–67]. Conversely, patients managed by controlled ventilation developed hypercarbia and acidosis, necessitating ventilatory changes.

Alexander *et al.* illustrated these observations in a study of 24 healthy patients undergoing laparoscopy at 20 mmHg with CO_2 pneumoperitoneum [68]. When comparing arterial blood gases obtained prior to insufflation and during laparoscopy, they observed an increase in PCO_2 by 8.6 mmHg and a decrease in arterial pH by 0.082 pH units after insufflation. These same authors subsequently demonstrated that this effect occurred only with CO_2 insufflation and not N_2O insufflation, thereby implicating CO_2 absorption from the peritoneal cavity, rather than hypoventilation, as the etiology of the hypercarbia and acidosis [69]. Likewise, Hodgson *et al*. [65] and Montalva and Das [70] observed that patients undergoing laparoscopy at intra-abdominal pressures of 15–20 mmHg developed significant hypercarbia despite being maintained at a constant minute volume. Montalva and Das demonstrated an increase in PCO_2 of 5 mmHg from pre- to post-insufflation in 10 female patients undergoing laparoscopy at a working pneumoperitoneum of 20 mmHg [70]. Hodgson *et al*. found a difference of 8 mmHg in the PCO_2 measured before and after insufflation to 15–20 mmHg in patients breathing spontaneously during laparoscopy; while in 10 patients maintained at constant minute volumes, the mean change in PCO_2 was 10.1 mmHg.

Collectively, these data imply that at 15–20 mmHg CO_2 pneumoperitoneum, significant quantities of CO_2 are absorbed from the peritoneal cavity during laparoscopy. Additionally, the absorption of CO_2 appears to reach a steady state between 15 and 30 min after the initiation of insufflation. Tan *et al.* measured CO_2 elimination in 12 patients undergoing pelvic laparoscopy to estimate CO_2 absorption during insufflation [71]. CO_2 excretion increased from 146 mL/min prior to insufflation to 183 and 172 mL/min at 15 and 30 min after insufflation, respectively. This translated into a rate of CO_2 absorption from the peritoneal cavity of 42 and 39 mL/min, respectively. Likewise, Mullet *et al.* measured CO_2 excretion at 2-min intervals after insufflation in 20 patients undergoing laparoscopic cholecystectomy (n = 10) or gynecologic laparoscopy (n = 10) [72]. In both groups, CO_2 excretion began to increase 8–10 min after the initiation of insufflation and reached a plateau by 15–20 min. The maximum increase in CO_2 excretion in the cholecystectomy group was 32 mL/min and in the gynecologic laparoscopy group was 18 mL/min, representing a 25% and 12% increase, respectively, from baseline.

Lister *et al*. further defined the relationship of CO_2 absorption during pneumoperitoneum in an experimental porcine model [73]. Twelve anesthetized pigs maintained at constant ventilatory parameters underwent CO_2 or helium insufflation in 5 mmHg increments from 0 to 25 mmHg. At each insufflation pressure, measurements were taken of CO_2 excretion (VCO_2), dead space, and hemodynamic parameters. In the CO_2 pneumoperitoneum group, CO_2 excretion increased in a nonlinear fashion with increasing intraperitoneal pressure, reaching a plateau at a pressure of 10 mmHg. In the helium pneumoperitoneum group, no increase in CO_2 excretion was noted. However, PCO_2 increased with rising intra-abdominal pressure in both groups, although the increase in PCO_2 was greater in the CO_2 group as compared to the helium group. Hemodynamic parameters were relatively stable at all pressures tested in both groups. The authors concluded that CO_2 absorption from the peritoneal cavity during insufflation reaches a maximum at a relatively low intra-abdominal pressure (10 mmHg). Until this point, there is a rapid increase in peritoneal surface area available for diffusion as intra-abdominal pressure increases. At higher pressures, limited additional surface area is available for further CO_2 absorption. However, PCO_2 continues to rise as a result of increasing dead-space ventilation. Finally, while the use of a helium pneumoperitoneum avoids the effects of direct CO_2 absorption from the peritoneal cavity, it produces the same ventilatory compromise secondary to increased intra-abdominal pressure.

In general, absorbed CO_2 is stored in the body tissues until it is eliminated by the lungs [74]. During brief periods of increased CO_2 absorption, alveolar and blood stores primarily mediate homeostasis. For longer intervals of CO_2 retention (i.e. during laparoscopy), skeletal muscle and visceral stores come into play as well [74]. The capacity of individual tissues to store CO_2 depends on their perfusion and storage capacity. Although bone is the largest potential reservoir, muscle may play a larger role in immediate CO_2 storage owing to its high perfusion rate [75]. According to Fowle and Campbell, an immediate storage capacity of approximately 40 mL for each mmHg rise in PCO_2 is available [76]. Therefore, if PCO_2 rises by 5–10 mmHg with a 20 mmHg CO_2 pneumoperitoneum, a corresponding 200–400 mL increase in CO_2 occurs. In the short term this excess CO_2 is buffered in the alveolar–arterial and visceral stores. However, potentially dangerous elevations in PCO_2 may result in serious hemodynamic alterations if compensatory changes in ventilation are not made. Furthermore, the need for elimination of excess CO_2 from visceral stores continues during the recovery phase after laparoscopy. With underlying pulmonary disease, elimination of CO_2 may be compromised, thereby necessitating prolonged mechanical ventilation in the postoperative period [77, 78].

Although hypercarbia associated with CO_2 pneumoperitoneum is recognized, the appropriate monitoring technique is controversial. Liu *et al.* prospectively evaluated 16 healthy patients undergoing laparoscopy using CO_2 pneumoperitoneum [79]. Capnography was used to measure end-tidal CO_2 during insufflation, while arterial blood gases were obtained intermittently to simultaneously assess arterial PCO_2. The authors noted good correlation between the two measurements. Specifically, end-tidal CO_2 increased from 31 to 42 mmHg while PCO_2 similarly rose from 33 to 44 mmHg during the procedure. Due to its noninvasive nature, capnography was recommended for monitoring healthy patients during laparoscopy. Wittgen *et al*. similarly observed concordance between capnography and arterial blood gas analysis in assessing PCO_2 in healthy patients undergoing cholecystectomy, but found capnography to be unreliable in estimating PCO_2 in patients with cardiopulmonary disease [77]. In 20 ASA class I patients, a small increase in PCO_2 and decrease in pH was noted after insufflation to 12–15 mmHg. Conversely, 10 ASA class II or III patients demonstrated a significant increase in arterial PCO_2 and decrease in pH after insufflation. However, no significant difference in end-tidal CO_2 was noted between the two groups after insufflation, suggesting that end-tidal CO_2 underestimated the arterial PCO_2 in the less healthy patients. Because of the poor correlation between end-tidal CO_2 and PCO_2 in patients with cardiopulmonary disease, invasive monitoring with arterial blood gas analysis is necessary to reliably evaluate them during laparoscopy.

The direct cardiovascular effects of hypercarbia are difficult to distinguish from sequelae due to increased intra-abdominal pressure during laparoscopy. Some hemodynamic changes occur irrespective of the insufflant, whereas others appear to be gas specific. In 10 healthy women undergoing laparoscopic tubal ablation, Motew *et al*. noted that CO_2 insufflation to 20 mmHg was associated with increased central venous and arterial pressure, tachycardia, and hypercarbia, although cardiac output remained unchanged [57]. Similarly, Liu *et al.* used transesophageal echocardiography (TEE) to measure cardiac output in 16 healthy patients undergoing laparoscopic cholecystectomy [79]. Although a significant rise in blood pressure was noted with insufflation, no change in cardiac output was measured.

Additionally, Marshall *et al*. noted no change in cardiac output in seven young women undergoing laparoscopic tubal ablation [80]. However, significant increases in central venous pressure, MAP, and heart rate occurred with insufflation to 15–21 mmHg. Other groups, however, have noted more substantial impacts on cardiac output and other measures of cardiovascular function [81, 82].

Several randomized trials compared the hemodynamic and respiratory consequences of high- and low-pressure CO_2 pneumoperitoneum during laparoscopic cholecystectomy. Wallace *et al*. randomized 40 patients to low-pressure (7.5 mmHg) versus high-pressure (15 mmHg) pneumoperitoneum and found no significant differences between the two groups with regard to PCO_2 or end-tidal CO_2, peak airway pressure, heart rate, cardiac index, stroke index, or MAP [83]. However, the decrease in cardiac index that was observed in both groups was greater and lasted longer in the high-pressure group. Somewhat in contrast, Dexter *et al.* observed that stroke volume increased from baseline in 10 patients undergoing low-pressure laparoscopy (7 mmHg) but decreased in 10 patients undergoing high-pressure laparoscopy (15 mmHg) [18]. Likewise, cardiac output remained at or below baseline levels in the high-pressure group. However, in the low-pressure group, after an initial decline in cardiac output, levels subsequently increased to 20% above baseline. These studies suggest that there may be a slight hemodynamic advantage to low-pressure laparoscopy.

Hemodynamic impact of patient positioning

Positioning during laparoscopy can influence hemodynamic parameters (Table 70.4). Williams and Murr demonstrated this in a canine experimental model by evaluating hemodynamic parameters in 10 dogs undergoing CO_2 insufflation in various positions [84]. In the horizontal position at pressures of 15 and 30 mmHg, cardiac output dropped to 79% and 77% of baseline, respectively. Positioning the animal head down resulted in a smaller reduction in cardiac output (86% of baseline at 15 mmHg, 82% of baseline at 30 mmHg) when compared to the horizonal position. Conversely, the head-up position further reduced cardiac output at both 15 and 30 mmHg pressure: 70% and 67% of baseline, respectively.

Table 70.4 Direct effects of patient position on hemodynamic parameters when compared to the supine position.

	Patient position	
Hemodynamic parameter	Head up	Head down
Heart rate	↑	↓
Mean arterial pressure	↓	↑
Systemic vascular resistance	↑	↓
Cardiac output	↓	↑
Intracranial pressure	↓	↑

Similar observations have been made in a clinical setting. Joris *et al.* noted hemodynamic parameters to be position dependent in 15 patients undergoing laparoscopic cholecystectomy at an intra-abdominal pressure of 14 mmHg [85]. Hemodynamic parameters were measured before and after induction of anesthesia, after positioning the patient head up, at various time intervals after insufflation and after desufflation. Induction of anesthesia with the patient supine prior to insufflation resulted in a 9% decrease in MAP and a 25% decrease in cardiac index. Tilting the patient to the head-up position further reduced the MAP by 17% and the cardiac index by 14%. With insufflation, the MAP increased by 37% and the cardiac index decreased by 18% compared to the head-up position prior to insufflation. Overall, MAP was unchanged and the cardiac index decreased by 50% from the preanesthesia value (from 3.6 to 1.8 L/min/m^2 at 5 min after insufflation). SVR and pulmonary vascular resistance increased by 107% and 128%, respectively. The authors suggested that the reduction in cardiac index may have been caused by increased afterload (SVR), as well as decreased venous return. The increase in SVR was likely a consequence of increased venous and arteriole resistance arising from increased intra-abdominal pressure, as well as from enhanced sympathetic activity resulting from elevated PCO_2. This study comprehensively demonstrated the cumulative effects of anesthesia, patient positioning, and insufflation on the hemodynamic status of patients undergoing laparoscopy.

Kelman *et al*. compared hemodynamic parameters in 39 patients undergoing gynecologic laparoscopy in either the horizontal (n = 21) or head-down position (n = 18) [86]. In the horizontal position, cardiac output rose from 3.9 L/min before insufflation to 4.5 L/min after insufflation to 10–20 cmH_2O. Baseline cardiac output was higher in the head-down position (4.8 L/min) compared to the horizontal position (3.9 L/min). After insufflation to 10–20 cmH_2O, cardiac output increased to 5.3 L/min in the head-down group. At an intra-abdominal pressure of 30–40 cmH_2O, however, cardiac output fell in both groups (4.4 L/min in the horizontal position and 4.8 L/min in the head-down position). The authors postulated that the changes in cardiac output reflected changes in central venous pressure; namely, patients in the head-down position had higher central venous pressures than patients in the horizontal position, and the cardiac output was correspondingly higher.

Unlike Kelman *et al.'s* study described above, Hirvonen *et al*. observed a decrease in cardiac index from baseline in 20 female patients undergoing laparoscopic hysterectomy in the head-down position when insufflated between 13 and 16 mmHg pneumoperitoneum [87]. Increases in pulmonary arterial pressure, central venous pressure, and pulmonary capillary wedge pressure were also noted. Similar observations were subsequently made by this group when studying a cohort of patients undergoing laparoscopic cholecystectomy [88].

In summary, three variables influence hemodynamic parameters during laparoscopy: intra-abdominal pressure, choice of insufflant, and patient position. For patients undergoing laparoscopy in the supine position, cardiac output is unaffected or decreases slightly with insufflation to low-to-moderate intra-abdominal pressures (10–15 mmHg). Higher intra-abdominal pressures (>20 mmHg) adversely affect cardiac output by decreasing venous return. Furthermore, urine output can decline significantly, although returns to normal shortly after desufflation. The choice of insufflant further contributes to the net hemodynamic effect. CO_2 insufflation can cause hypercarbia, which has a stimulatory effect on the circulatory system, thereby increasing heart rate, stroke volume, and myocardial contractility, while decreasing peripheral vascular resistance. Conversely, absorption of inert gases such as helium generally manifest with no additional hemodynamic changes. The head-down position results in favorable hemodynamic changes. Here, cardiac output is higher than in the supine position, but is still dependent on intra-abdominal pressure. Of note, ICP increases in the head-down position, which could be potentially dangerous in select patients already at risk for increased ICP.

Stress response and immunologic factors

Trauma related to surgery is known to stimulate systemic inflammatory and immune responses. Furthermore, alterations in the stress and immune response correlate with the severity or extent of injury [89] such that the physiologic response to laparoscopic surgery may differ from that of open surgery. Additionally, insufflation (particularly by CO_2) may play a contributing role in systemic immune response.

Acute-phase reactants

The primary mediators of the acute-phase response are the inflammatory cytokines interleukin-1 (IL-1), IL-6, and tumor necrosis factor (TNF), which are released from peritoneal macrophages [90]. The hepatic component of the acute-phase response is regulated by IL-6, which stimulates production of acute-phase response proteins, including C-reative protein (CRP), which is the primary marker [91, 92]. TNF and IL-1β mediate the nonhepatic manifestations of the acute-phase response, such as fever and tachycardia [91].

IL-6 is an early marker of tissue damage and levels rise in proportion to tissue trauma. A number of investigators have compared serum IL-6 levels following laparoscopic and corresponding open operations. When specifically considering gallbladder removal, numerous series have demonstrated significantly higher levels of IL-6 associated with open versus laparoscopic cholecystectomy [93–95]. Some groups have also observed a correlation between peak IL-6 and CRP levels [96, 97]. In contrast, results for laparoscopic-assisted colon resection are less definitive. In a nonrandomized trial comparing laparoscopy-assisted with open colon resection, Harmon *et al.* detected reduced IL-6 levels with the laparoscopic approach [98]. Subsequently, Leung *et al.* reported a randomized trial of 34 patients with organ-confined rectosigmoid carcinoma managed by laparoscopy-assisted or open colon resection. These authors observed significantly lower IL-6 and IL-1β levels following laparoscopic surgery [99]. Conversely, Stage *et al.* measured higher levels of IL-6 and CRP in the laparoscopic cohort among a mixed group of patients randomized to laparoscopy-assisted or open colectomy [100]. It is likely that differences in patient and tumor characteristics in study groups account for the discrepancies in these studies.

CRP is one of the most extensively studied acute-phase reactants following surgery. CRP rises 4–12 h following surgery, peaks at 24–72 h, and remains elevated for approximately 2 weeks [101]. Most studies demonstrate modest increases in CRP following laparoscopic versus open surgery [94, 97, 99, 102–104], although a few groups observed no difference in acute-phase response proteins between the two groups [105, 106].

Influence of insufflation agent

The impact of specific insufflation agents on immune function has been studied both experimentally and clinically. Chekan *et al.* compared the immune competence of mice (determined by ability to clear an intraperitoneally administered intracellular pathogen) following abdominal laparotomy or laparoscopy with CO_2 or helium as insufflant [105]. All interventions were associated with impaired cellular-mediated immunity (decreased clearance of interperitoneal bacteria), although CO_2 pneumoperitoneum resulted in a lower bacterial clearance rate than either laparotomy or helium pneumoperitoneum. Of note, mice with helium pneumoperitoneum demonstrated the best clearance rates.

Similarly, West *et al*. demonstrated significantly lower levels of TNF and IL-1 in response to bacterial lipopolysaccaride when macrophages were incubated in CO_2 compared with air or helium [107]. They further proposed that the impairment in macrophage cytokine production was due to intracellular acidification as a result of the CO_2 pneumoperitoneum [108]. Conversely, Sandoval *et al*. found no impairment in natural killer cell activity in rats subjected to CO_2 pneumoperitoneum [109]. Clinically, Sietses *et al.* randomized 33 patients undergoing laparoscopic cholecystectomy to CO_2 insufflation, helium insufflation, or an abdominal wall-lifting technique, and measured systemic immune response [110]. These authors noted that CRP levels were significantly higher in the helium and abdominal wall-lifting groups, suggesting that incision size alone is not responsible for differential immune responses. Other variables related to the pneumoperitoneum have also been investigated to assess for effect on immune function. In a randomized clinical trial of laproscopic cholecystectomy, cytokine production was attenuated when using warmed compared with room temperature CO_2 [111].

Other markers

Beyond cytokine and inflammory markers, the stress response, as measured by neuroendocrine factors has been compared between laparoscopic and open surgery. In a randomized trial comparing laparoscopic and open cholecystectomy, Karayiannakis *et al.* detected significantly higher levels of cortisol, epinephrine, and norepinephrine in the postoperative period after open cholecystectomy [112]. Likewise, LeBlanc-Louvry *et al.* found reduced levels of adrenocorticotropin hormone as well as urinary cortisol and catecholamine metabolites in patients randomized to laparoscopic versus open cholecystectomy [113]. Conversely, Hendolin *et al*. found no significant differences in plasma cortisol or catecholamines between patients undergoing laparoscopic versus open cholecystectomy in a randomized trial [114].

Overall, the effects of CO_2 insufflation on the stress response continue to be discovered. There are divergent data regarding the effects of CO_2 on immune function. Further correlation of the immune and stress response and immunolgic outcome is required in order to determine their significance with regard to laparoscopic complications, postoperative recovery, and tumor implantation or metastasis.

Complications

Adverse effects can occur secondary to either the establishment or maintenance of pneumoperitoneum. Hemodynamic and ventilatory sequelae are discussed above. However, a number of complications can occur due to misplacement of the Veress needle and/or trocar with subsequent insufflation.

Subcutaneous emphysema is the most common manifestation of a poorly positioned Veress needle or trocar. In this case leakage of CO_2 around the trocar or direct insufflation of CO_2 into the subcutaneous or properitoneal tissues results in dissection of gas along extraperitoneal tissue planes. Generally, subcutaneous emphysema is harmless, but in certain instances it can lead to hypercarbia [115–117]. Wolf *et al.* found that subcutaneous emphysema was one of several factors, including increased duration of insufflation and an extraperitoneal approach, that correlated with increased CO_2 absorption (as measured by CO_2 excretion) during pelvic laparoscopy [115]. Unlike intraperitoneal gas, retroperitoneal or extraperitoneal gas is not limited by the peritoneal membrane. As such, it may traverse a variety of tissue planes to enter the pleural or extrapleural space, mediastinum, or pericardium. Dissection of gas along the great vessels or from the anterior neck allows entrance into the mediastinum [118]. From the mediastinum, gas may rupture into the pericardium or travel along the pulmonary vessels to the pleural space, resulting in pneumopericardium [119–121] or pneumothorax [118, 122, 123], respectively. Generally, in the absence of hemodynamic or respiratory compromise, small pneumothoraces may be managed conservatively. Large or symptomatic pneumothoraces are treated with needle aspiration or tube thoracostomy.

A potentially fatal complication of pneumoperitoneum is gas embolism [124–126]. Typically, the Veress needle is inadvertently positioned in a vein, resulting in infusion of gas directly into the venous system. The gas bubble travels to the right heart and lodges in the atrium or pulmonary arterial system. The gas lock may obstruct venous return to the atrium, resulting in a precipitous fall in cardiac output, or it may block pulmonary blood flow, causing pulmonary hypertension and right heart failure. The diagnosis is suggested by dramatic, sudden cyanosis, hypoxia, hypercarbia, arrhythmia, or hypotension during insufflation. The classic mill wheel murmur is pathognomonic, but variably present. Capnography may be useful in the early diagnosis of gas embolism [124, 127]. An abrupt decrease in end-tidal CO_2 may be the first sign of a gas embolism; the “air lock” completely obstructs pulmonary blood flow, leading to the decrease in CO_2 excretion [128]. However, the most sensitive means of detecting gas embolism is TEE, which can detect a bolus of CO_2 as small as 0.02 mL [129]. Experimentally, Couture *et al.* compared the sensitivity of TEE, end-tidal CO_2, pulmonary artery pressure, and precordial auscultation for detecting CO_2 embolism in anesthetized pigs, and found that TEE was superior to the other modalities, which were of comparable sensitivity, in detecting gas embolism [130].

Although venous gas embolism occurs most commonly as a result of Veress needle misplacement and insufflation into a large vein, embolism as a result of venous injury during pneumoperitoneum is also a theoretical concern [131, 132] Experimentally, O'Sullivan *et al*. detected gas emboli after 20 of 22 venotomies created in anesthetized pigs undergoing laparoscopy with CO_2 pneumoperitoneum at 10–25 mmHg pressure [129]. The degree of embolization correlated with the decrease in central venous pressure due to blood loss or distal venous compression, the duration and amount of manipulation of the venotomy, and intraperitoneal pressure. As such, in the event of significant venous injury during laparoscopy, intravascular volume should be maintained and the site of bleeding should be occluded directly.

Treatment of gas embolism consists of immediate desufflation, initiation of 100% inspired oxygen, and resuscitative measures. In addition, the patient is turned laterally and placed head down with the right side up. In this position further air is prevented from entering the pulmonary circulation and the air bubble can theoretically be aspirated with a central venous catheter placed in the right atrium.

Cardiac dysrhythmias have also been associated with laparoscopy. Carmichael reported three cases of marked bradycardia that occurred shortly after initiation of CO_2 insufflation [133]. He postulated that reflex vagal stimulation from stretching of the peritoneum accounted for the bradycardia. Two additional cases of cardiac dysrhythmia, both ventricular in nature, were also reported in this series. In these cases, ventilatory insufficiency was theorized to be responsible for the cardiac response. Scott and Julian reviewed 100 consecutive patients undergoing laparoscopy using CO_2 insufflation and compared them to 45 patients undergoing laparoscopy with N_2O insufflation [134]. Among the patients undergoing CO_2 insufflation, 17% experienced cardiac arrhythmias compared with only 4% of the N_2O patients. The arrhythmias were characterized primarily by extrasystolic ventricular beats. In addition, the postinsufflation PCO_2 was significantly higher in the CO_2 insufflation patients versus the N_2O patients, leading the authors to attribute the higher incidence of arrhythmias in the CO_2 group to the hypercarbia.

Low-pressure and gasless laparoscopy

Irrespective of insufflation agent, pneumoperitoneum can be associated with adverse effects attributable to increased intra-abdominal pressure and/or absorption of insufflant. In an attempt to avoid these potential problems, a number of investigators have examined the use of low-pressure pneumoperitoneum and gasless laparoscopy. Banting *et al*. described an abdominal lift device that suspends the abdominal wall, thereby reducing the intra-abdominal pressure needed to create a working space [135]. A 10–12-mmHg pneumoperitoneum was initially established and the lift device employed under endoscopic vision. An external hook-and-chain assembly secured to the side of the table was used to provide traction to suspend the anterior abdominal wall. They used this device in eight patients with cardiopulmonary disease; with use of the abdominal wall lift, a working pneumoperitoneum of only 6–8 mmHg was necessary to successfully perform cholecystectomy.

Araki *et al*. used a similar device in 151 patients undergoing laparoscopic cholecystectomy [136]. A low-pressure pneumoperitoneum (4 mmHg) was established to allow placement of the abdominal wall retractor. In 121 patients the abdomen was desufflated after the gallbladder was identified; in 30 obese patients the pneumoperitoneum was maintained until the cystic duct and artery were secured. No adverse effects were attributable to the abdominal wall-lift device. End-tidal CO_2 was recorded before pneumoperitoneum, during pneumoperitoneum, and after desufflation. End-tidal CO_2 was 29, 35, and 30 mmHg, respectively. Simarly, Kitano *et al*. prospectively randomized 83 patients with symptomatic gallstones to laparoscopic cholecystectomy using either traditional CO_2 pneumoperitoneum or a U-shaped abdominal lift retractor [137]. The laparoscopic procedure was completed in 88% of patients in the pneumoperitoneum group and in 100% of patients in the abdominal wall retractor group. When the gallbladder was severely fibrotic, the success rate was higher in the retractor group (100% of six patients) compared with the pneumoperitoneum group (12% of six patients). The authors concluded that the abdominal lift device was safer and more efficacious than traditional pneumoperitoneum for laparoscopic cholecystectomy.

Gasless laparoscopy has become easier with the development of commercial abdominal retractors/elevators secured to the side of the operating table (e.g. Laparolift, Origin Medsystems, Menlo Park, CA, USA). As in the studies noted above, all abdominal lift devices mechanically elevate the anterior abdominal wall away from the intra-abdominal organs, thereby creating a working space and eliminating the need for insufflation. Such instruments have been used for a host of laparoscopic procedures, including pelvic lymph node dissection, repair of a traumatic gastric perforation, herniorrhaphy, cholecystectomy, and appendectomy [138–140].

Conclusions

The vast majority of laparoscopic procedures can be safely performed with a CO_2 pneumoperitoneum. The physiologic consequences of increased intra-abdominal pressure and absorption of CO_2 from the peritoneum are generally well tolerated in the healthy individual on controlled ventilation. Because of the problems of hypercarbia, alternative gases such as helium should be considered in debilitated patients with cardiopulmonary compromise. Finally, particularly in the high-risk patient or the patient at risk for increased intracranial pressure, gasless laparoscopy or low-pressure pneumoperitoneum may likewise provide comparable visibility and working space to the CO_2 pneumoperitoneum, but without the associated adverse consequences.

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CHAPTER 71

Laparoscopy: Basic Instrumentation

Khaled Shahrour & Stephen V. Jackman

Introduction

Many advances in laparoscopy are due, in large part, to development of innovative laparoscopic instrumentation. Only the surgeon's imagination and the willingness of industry to produce new equipment limit the development of devices. Due to the progression of various modalities of laparoscopy, such as hand-assisted, robot-assisted, and single-port laparoscopy, specific instruments for these types of procedures will be discussed in their respective chapters. In this chapter, we describe the current state of the art in basic laparoscopic instrumentation with the goal of increasing the surgeon's knowledge of the devices available to assist them as part of any laparoscopic procedure. Many of these instruments and techniques for their use in certain procedures are described in detail in subsequent chapters.

Visual system

Excellent visualization is essential for optimal completion of the procedure. Fine dissection, the ability to anticipate instrument needs, and teaching are enhanced by the availability of this image for the surgeon and other participants. A high-resolution magnified image of the operative field (up to X20) is a significant advantage of laparoscopy [1]. The cost of such magnification is the limited two-dimensional (2D) field of view and the occasional loss of visualization due to fogging, soiling, or equipment failure. The components of the visual system include the endoscope, light source, camera, video monitor, and recording device.

Endoscopes

The conventional laparoscope is a rod–lens, fiberoptic, or camera-on-a-stick endoscope. They are available in fixed and movable configurations with straight (0°), angled (commonly 30°, 45°, and 70°), and flexible tips that can deflect in four directions. Working endoscopes are rarely used because of lower quality of images. Sizes range from 2.7-mm "needlescopes," that can pass through a Veress needle, to 12 mm in diameter. Light transmission decreases as angle increases and size decreases, which can be problematic, especially if there is bleeding in the field. A recent development is the LTF-VP EndoEye (Olympus, Center Valley, PA, USA), which is a 5-mm endoscope with a deflectable tip allowing 100° field of view in all directions (Figure 71.1).

Laparoscopists have to cope with the challenge of using 2D display to represent a 3D reality as depth perception is lost. 3D Systems with head-mounted displays or special glasses were developed in order to reproduce binocular vision. Most 3D systems have two lenses to maintain binocular vision. Although many studies have shown that 3D systems improve surgical task performance [2], the operator discomfort, high costs, and complicated instrumentation have limited the spread of the technology, except in robotics. Surgeons have complained of dizziness because of disparities in focus, zoom, and alignment between the two separate images of the two cameras [3].

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Image not available in the electronic edition

Figure 71.1 (A) The LTF-VP EndoEye has a low profile handle; (B) the scope has a flexible tip with a camera-on-a-stick configuration (courtesy of Olympus Medical).

The Endosite 3Di visual system (Viking Systems Inc, San Diego, CA, USA) consists of a laparoscope with dual three-chip charge coupled device (CCD) cameras, and a headset worn by the surgeon. A "next generation" model with high-definition (HD) camera is being developed. A study compared 27 subjects with various laparoscopic experience performing three specific tasks (peg transfer, ring manipulation, and cannulation) on a standard laparoscopic trainer using standard 2D laparoscopes, the Endosite system, and the da Vinci Robotic system [4]. The authors concluded that there was improved performance with 3D optics in some complex tasks, such as peg transfer, but not in overall results.

A novel 3D system uses only one camera by using the difference in light density between objects. The system has a plate in the middle of the scope for turning the axis to bend the light. Using the plate, the images from two different paths of light corresponding to two images for the left and the right eyes are captured by the single camera. This novel technology is claimed to eliminate the possible dizziness that occurred with previous 3D systems [5].

Light source

Light is transmitted through the laparoscope via fiberoptic cable from the light source. Halogen, mercury, and xenon bulbs are the most common sources of high intensity light. Cool Wave (Wave Visions, Vadodara, India) is a light-emitting diode (LED) source that is available for use in laparoscopy with the advantages of lower energy consumption, longer life, and less heat production. Fiberoptic technology enables efficient light transmission between the light source and the tissue target. Integrated light source and camera systems allow for automatic adjustment of light intensity. Damage to fiberoptic cables will reduce light throughput and should be prevented. Transparent cables allow detection of cable damage.

Camera

The camera system consists of the camera box and camera head. The camera box processes the image for output to the monitors. Adjustments commonly include white balance, gain, zoom, light intensity, and shutter. The camera can be integrated into the laparoscope, either at the back or at the distal tip. The later configuration provides improved quality as the images are processed directly. The quest for better visual discrimination led to the development of single- and three-chip CCD cameras. Three-chip cameras provide better resolution and color but are heavier and more expensive. Comparison between HD, with a CCD at the tip, and standard definition laparoscopes showed improved image resolution (the minimum distance between two lines that can be identified at a certain distance), lower distortion (the alteration in the original image), greater depth of field (the in-focus distance range), and increased image luminous flux (light energy in a unit of time) with HD use despite having used a standard video monitor. The same study showed equivalent color reproduction (ability to match the original red, green and blue colors when they are recombined), grayscale discernment (represents the discrimination of shades of color), and field of view (the angular visual extent of an object at any moment) in both modalities [6]. Subjectively, many studies show that HD cameras contribute to improved surgical task performance even when compared to standard definition three-chip CCD cameras [7]. The high cost of HD systems is a limitation.

Video monitor

Standard high-resolution cathode ray tube (CRT) monitors are increasingly being replaced by the lighter flat-screen liquid crystal display (LCD) monitors. This allows for easier and more ergonomic positioning using lightweight booms. Projection systems placing the image directly over the patient offer potentially the most intuitive images but suffer from lack of brightness and resolution.

Recording device

Any type of video capture device can be adapted to document laparoscopic procedures. Still photos and DVD are giving way to USB-based flash memory and portable hard drive recording devices.

Ultrasound probes

Most laparoscopic ultrasound probes have a linear-array transducer mounted on a flexible tip with a frequency range of 4.0–10.0 MHz [8]. They are useful for obtaining proper margins in procedures such as partial nephrectomy and cryoablation of renal tumors, especially if they are endophytic tumors.

Access system

Complications during laparoscopy may occur at the time of initial access to the abdominal cavity [9]. The closed technique using the Veress needle followed by blind insertion of a cutting trocar is replaced by safer techniques, including dilating-tip trocars, visual obturators, and variations of the open Hasson technique [10]. Balloon dissection may be used to rapidly develop retroperitoneal or retropubic spaces.

Insufflation

Pneumoperitoneum or pneumoretroperitoneum creates and maintains the working space for laparoscopic procedures, although many reports suggest that pneumoperitoneum is not necessary for safe access using an optical trocar [11]. CO_2 gas is used because of its availability, lack of combustibility, and solubility in blood. The acidosis caused by CO_2 is compensated by increased ventilation in all but the most severe pulmonary patients. These same patients are those for whom a large incision would be most detrimental postoperatively, and thus, poor pulmonary status is not an absolute contraindication to laparoscopic surgery. Helium, which is less soluble in blood, can be used in cases of severe hypercarbia. Other noble noncombustible gases are rarely used because of high costs and insolubility that may lead to gas embolus formation.

Insufflation pressure and gas flow are controlled with an insufflator. Initial gas flow rate is commonly set at 1–3 L/min until entry is deemed safe. The flow can then be increased to maximum (20–40 L/min), but will be limited by the size of the inflow device (Veress or port) and presence of partially-obstructing instrumentation in the device. Heated and humidified insufflations may reduce peritoneal irritation and pain [12].

Insufflation pressure is set initially at 15 mmHg and usually ranges between 8 and 20 mmHg during the case. Higher pressures improve working space and hemostasis, but the trade-off is higher gas absorption that can be a problem if not compensated by increased ventilation. Higher pressure can increase postoperative pain in minor procedures, but is not a factor in the majority of urologic laparoscopic procedures [13].

Veress needle: closed technique

Initial access to, and insufflation of, the peritoneal space is still commonly performed using a Veress needle (Figure 71.2). The needle consists of an inner

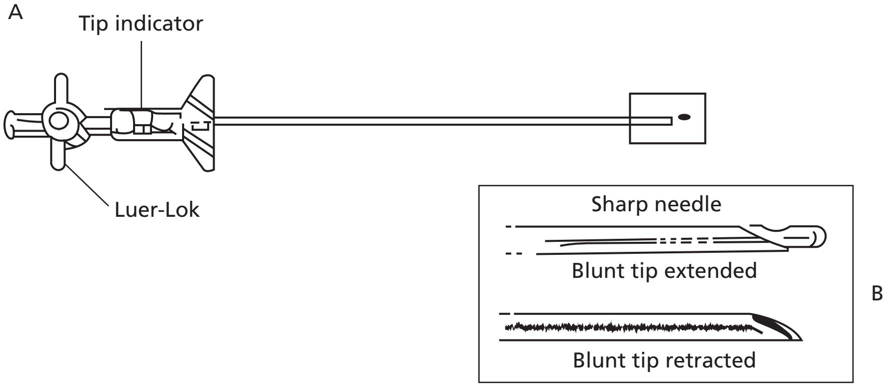

Figure 71.2 (A, B) The Veress needle tip has an inner blunt core that retracts when encountering resistance from tissue, but pops forward once the needle is in the peritoneal cavity.

spring-loaded blunt tip and an outer sharp sheath. The blunt tip is compressed and the sharp sheath is exposed when the needle is pressed against firm structures such as fascia. The blunt tip then springs out to prevent injury to more compliant structures, such as bowel. Reusable and disposable versions are available. Veress needles allow rapid access to the virgin abdomen in multiple possible locations. In patients with a history of prior abdominal surgery, it can often still be used safely if inserted in the quadrant furthest from possible adhesions [14].

Trocars

Trocars maintain pneumoperitoneum and allow fast and safe introduction of instruments into the abdominal cavity. Trocars typically contain an outer sheath and an inner sharp obturator. There are various sizes and lengths of disposable and nondisposable trocars ranging from 3 to 20 mm. An ideal trocar should cause decreased tissue injury, bleeding, trocar-site pain, and risk of herniation, in addition to having an easy entry and tight fascial seal to prevent dislodgments and gas leak, and eliminate wound closure. Cutting trocars offer rapid access to the peritoneal cavity, but their safety in initial port placement is questioned, especially in the previously operated abdomen. Even in secondary port placement under direct vision, there exists a risk of laceration of body-wall blood vessels. Transillumination is useful to detect blood vessels, but is not possible in many cases. Also, the fascia needs to be closed if a cutting trocar of 10 mm or larger is used.

Dilating-tip or nonbladed trocars are preferred as they do not cut through the abdominal wall. The tips are typically cone shaped, often with laterally placed fins to assist in the dilation of the abdominal wall muscles. Advantages include smaller fascial openings after port removal not requiring closure, with less chance of hernia and a higher likelihood of pushing aside rather than lacerating blood vessels and muscles [15]. Disadvantages include a higher insertion force and increased difficulty penetrating compliant structures such as the peritoneum and bladder [16, 17].

One of these noncutting trocars is the Step Needle/Sleeve trocar system (US Surgical, Norwalk, CT, USA); after being inserted with a small needle port, its sleeve expands with passage of a dilating obturator up to 12 mm (Figure 71.3). The fascial defect caused by the Step trocar is 50% smaller than that of cutting trocars [18]. The price of the trocar system has limited its widespread application, although it had lower rates of wall bleeding and of dislodgment without any herniation, despite nonclosure of the port site, in a prospective randomized trial of 250 patients [19].

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Figure 71.3 Mesh sleeve of the Step System (US Surgical, Norwalk, CT, USA) can be placed in an open fashion or used with a Veress needle as shown. The cannula and dilator are then passed through the sleeve (copyright © 2011 Covidien. All rights reserved. Used with the permission of Covidien).

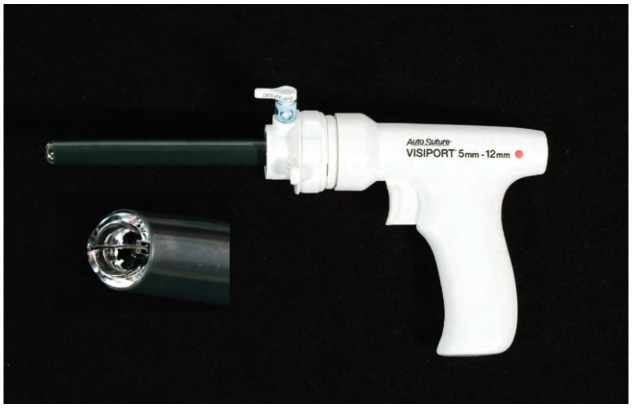

Figure 71.4 The Visiport (US Surgical, Norwalk, CT, USA) uses a recessed blade that extends out of the end of the obturator as the surgeon fires a trigger.

Visual obturators are systems combining a sheath, a cutting or dilating element, and a laparoscope, to allow direct visualization of the layers and blood vessels of the body wall during entry (Figures 71.4 and 71.5). The Optical Separator (Applied Medical Inc, Rancho Santa Margarita, CA, USA) is one such device. Its clear tip allows the surgeon to pass an endoscope into the trocar

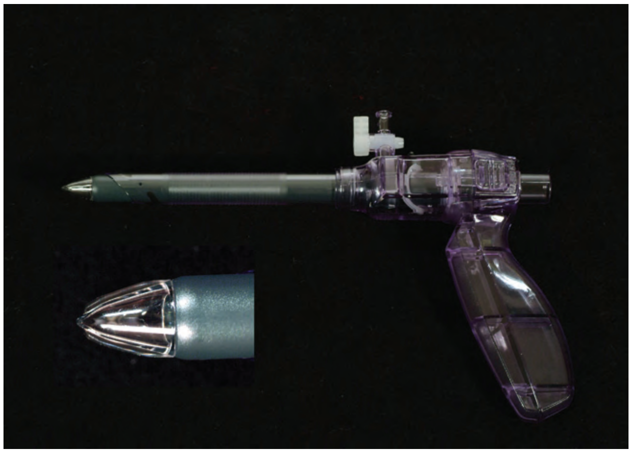

Figure 71.5 The Optiview (Ethicon Endo-Surgery, Cincinnati, OH, USA) uses two sharpened plastic fins on the tip of the trocar.

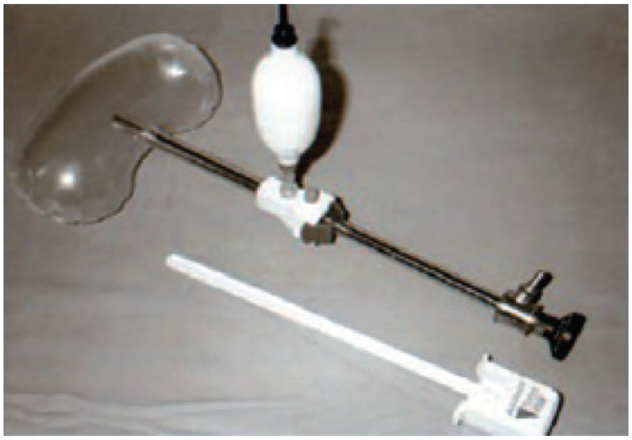

Figure 71.6 With the Preperitoneal Distention Balloon System (US Surgical, Norwalk, CT, USA), the retroperitoneal space can be balloon developed under direct vision.

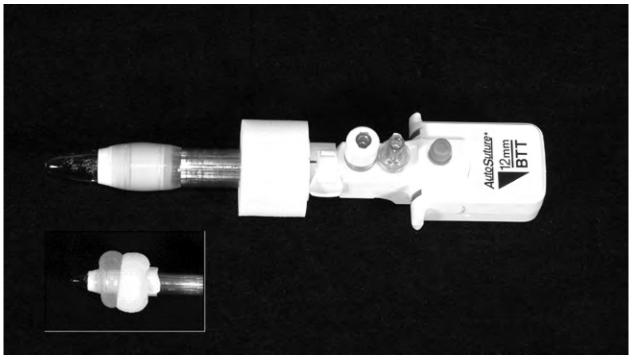

Figure 71.7 The Blunt-tipped Trocar (US Surgical, Norwalk, CT, USA) uses a balloon, which is inflated after insertion through the entry site, and a sliding foam collar to seal the trocar site at the fascia. Only a small amount of the trocar protrudes into the working space.

to monitor its passage through the abdominal wall. These devices can also be used initially for insufflation, as mentioned above.

Open access devices

Open access to enter the abdominal cavity is a viable option, particularly in pediatrics and patients with prior surgery. Disadvantages include the possibility of gas leak, having a larger incision than needed, and increased difficulty in obese patients. The Step system can be used in a modification of this method to solve some of these problems by inserting the mesh sleeve and dilating it after making a 2–3-mm incision of fascia and peritoneum.

Another modification of the Hasson technique for access to nonperitoneal locations is use of a balloon to rapidly develop the space. The Preperitoneal Dissection Balloon System (US Surgical) and Spacemaker II Balloon Dissector (US Surgical) allow direct observation during space creation (Figure 71.6). The initial incision needs to be sealed by a balloon-tipped or Hasson trocar. The Blunt-tipped Trocar (US Surgical) is a significant advance over the standard Hasson trocar as the balloon at the distal end holds it in place and the sliding foam ring proximally seals it to the abdomen (Figure 71.7).

General instrumentation

Articulated versus nonarticulated instruments

Part of the difficulty in performing certain laparoscopic tasks such as intracorporeal suturing and knot tying is due to the fact that conventional laparoscopic instruments are not articulated. Robotic technology allowed the use of the flexible EndoWrist technology, which provides equivalent degrees of freedom (DOF) to that of open surgery. Handheld articulating instruments have been developed to reproduce the extra DOF available in robotics. Such instruments may facilitate intracorporeal suturing, especially in difficult positions such as the deep pelvis, and have a potential role in single-port surgery to assist in re-establishing triangulation [20]. However, the complexity of instrument maneuvering may make it harder to predict the movement outcome and coordination between the hand and tool. Also, another disadvantage of these instruments is that they inherently lack sufficient strength to provide robust retraction and dissection. A novel approach to make up for the weaknesses of articulation is the use of bent instruments such as HiQ LS (Olympus), which have a double curved shaft. The benefit of reticulating and bent instruments is more relevant in single-port surgery than conventional laparoscopy.

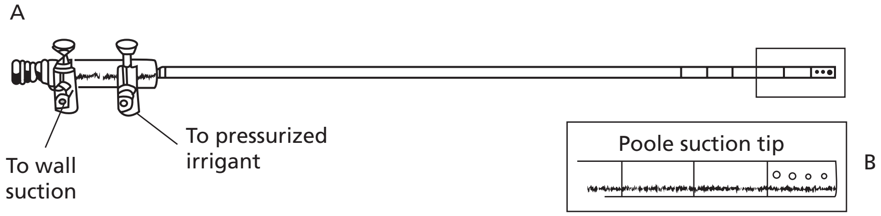

Figure 71.8 (A) Combined irrigator–aspirator has a trumpet valve mechanism for separately activating irrigation and suction; (B) Poole suction tip.

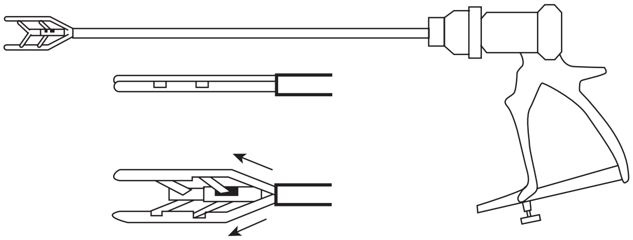

Figure 71.9 Reusable PEER retractor (Jarit Surgical Instruments, Hawthorne, NY, USA) is available in 5 and 10 mm sizes, which expand to provide a 20+ or 40+ mm surface for retraction.

Irrigator–aspirator

The irrigator–aspirator is an essential tool for both cleaning up the operative site for optimal visualization as well as dissection. The Poole suction design and blunt tip of most devices minimize impaction of tissue by the device and allow gentle bursts of suction to be used to tease tissue planes apart (Figure 71.8).

Retractors

Safe retraction of organs, such as the liver and bowel, is often necessary for access to the operative site. When adequate gravity retraction is not possible, numerous instruments are available. Expanding retractors are variations on the design of a straight 5- or 10-mm instrument that transforms into a wider configuration once inserted and can be attached to a table mount (Figure 71.9).

The Diamond Flex 80-mm Angled Triangular Liver Retractor (Genzyme Surgical Products Corporation, Tucker, GA, USA) is a long multijointed instrument that passes through a 5-mm port and then transforms into a rigid triangular shape after tightening its knob (Figure 71.10). Disadvantages include the initial cost and the metal construction that does not hold organs as securely as some disposable devices. Other variations of retractors, such as balloon, fabric, and fan, are available from several manufacturers. There are also needleoscopic or peanut retractors. Retraction of some structures during laparoscopy can be accomplished using a suture on a straight needle passed directly through the skin and anterior abdominal wall, around the structure, and back through the abdominal wall.

Instrument holders

Several mechanical instrument holders have been developed to take the place of the assistant. The instrument is positioned and locked in place. Camera holders can be either active (motorized) or passive (without a motor), while instrument holders are only passive. The basic Martin Arm (Mick Radio-Nuclear Instruments Inc, Mount Vernon, NY, USA) is a multijointed stainless steel arm requiring each joint to be positioned and hand tightened. The Unitrac Retraction System (Aesculap, Center Valley, CA, USA) uses compressed air to allow pneumatic locking with a single button (Figure 71.11). Other similar instruments include the Endoholder (Codman Inc, Cincinnati, OH, USA) and the TISKA Endoarm (Karl Storz, Endoskope, Tuttlingen, Germany), which assist with trocar and instrument positioning at a fixed point at the trocar puncture site. The Endoholder is an adjustable spring-loaded articulating holder that has a precision clamp to accommodate instruments of various sizes. The Flex Arm (Mediflex Surgical Products, Islandia, NY, USA) is a table-mounted flexible metallic arm that can hold retractors, instruments, and endoscopes in position, thus lowering the need for an experienced assistant. The disadvantages of these holders include the inability to determine the force that is applied to the instrument and the need to manually readjust their positions when needed.

Active camera holders have diverse interfaces to allow their control by the surgeon. The interface can be voice, foot, or hand controlled, or automatic instrument tracking. Active or robotic camera holders such as FreeHand (Prosurgics, Cupertino, CA, USA) allow the surgeon to control the endoscope with gentle, natural head movements, and replace the need for an experienced assistant to hold the camera. The LapMan (Medsys, Gembloux, Belgium) is a hand-controlled holder using a joystick that is placed under the surgeon's glove.

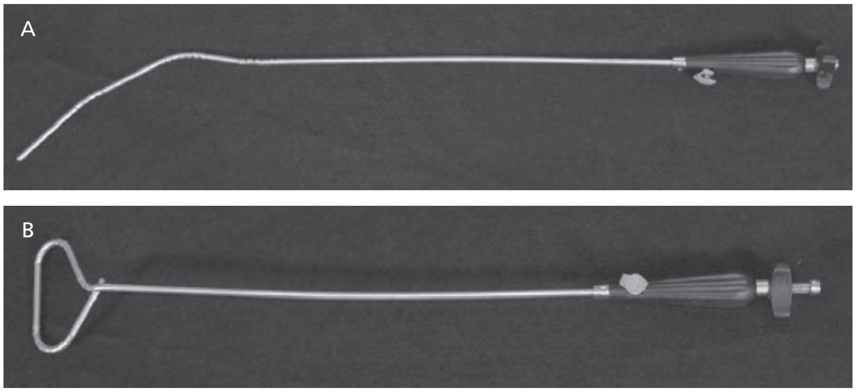

Figure 71.10 (A) Diamond Flex 80-mm Angled Triangular Liver Retractor (Genzyme Surgical Products Corp, Tucker, GA, USA) fits through a 5-mm cannula. (B) Twisting the handle converts the retractor to a rigid, angled triangular shape with large surface area.

Graspers and dissectors

Basic laparoscopic grasping, dissecting, and cutting instruments are available from many manufacturers and are quite similar. They vary in size (2–12 mm), handle type (inline or scissor grip), action (single or double), jaw curvature, ability to lock, rotate or reticulate, and presence of insulation for electrocautery use. The tips vary between blunt, pointed, curved, angled, and straight. The surface of the jaws can be traumatic (toothed) to hold tissue or atraumatic (smooth or serrated) for gentle tissue manipulation.

Five-millimeter scissor-handle, rotating, insulated, curved jaw instruments are the most commonly used. High-use basic instruments include the curved atraumatic grasper (Maryland type), atraumatic locking bowel grasper, curved scissors, and hook electrode. Laparoscopic peanuts are frequently used for blunt dissection between planes [21]. Surgeons develop their own preferences in choosing specific instruments with training and experience.

Incising instruments

Various modalities and instruments are used for incising tissue in laparoscopy. Some of these incising instruments, such as the scalpel or scissors, have limited or no hemostatic action, while other instruments have a combined action, such as ultrasound instruments (see below). Curved-tip laparoscopic scissors are the main type used for dissection, either mechanically (cold cut) or electrically (hot cut). A laparoscopic scalpel is available, although its role is very limited and its safety is questionable. Electrosurgical incision is done through various electrode configurations; needle, spatula, cutting, and hook. The thinner the metallic tip of the probe, the higher the density of the electrical current and thus the greater the cutting power.

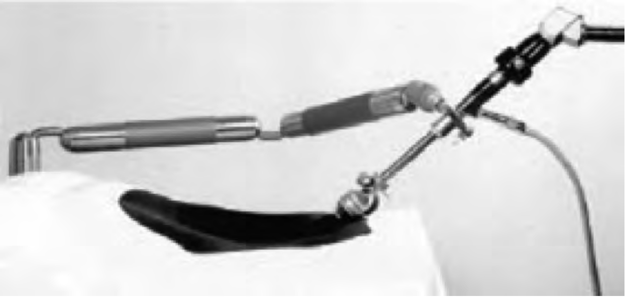

Figure 71.11 Unitrac Retraction System (Aesculap, Center Valley, CA, USA) is locked into place with compressed air. It can hold various instruments for retraction (courtesy of B. Braun Medical Ltd).

Laser

CO_2, neodymium:yttrium–aluminum–garnet (Nd:YAG), holmium, and potassium titanyl phosphate (KTP) are the lasers that can be used for incision and cutting through the working channel of the laparoscope. Some types, such as the holmium:YAG, can coagulate tissue at the same time. However, laser is not used frequently in laparoscopic urology.

Specialized instrumentation

Hemostatic instruments

Energy-based instruments

There are multiple instruments that employ different energies to seal tissue. These devices also use various feedback mechanisms, except for the conventional monopolar electrocautery, which does not have any feedback mechanism. In general, energy is delivered in a high-voltage and low-current burst that is combined with a feedback mechanism from the energy source to evaluate the tissue and the corresponding current that is needed.

Electrocautery

Monopolar cautery is a high-frequency current delivered from a single electrode at the site and is used mainly for hemostasis of small vessels during dissection. Undiagnosed injuries from stray energy occur when the monopolar current is not completely localized to the visible part of the instrument, due to either unrecognized breaks in the insulating coating or to capacitative coupling [22]. Monopolar electrocautery accounts for more than half of the reported laparoscopic bowel injuries [23]. Active electrode monitoring (AEM) or insulation scanners can minimize cautery injury. The AEM System (Electroscope Inc, Boulder, CO, USA) includes laparoscopic instruments that are simultaneously connected to an electrocautery machine and to a separate device that searches for stray energy. The AEM System deactivates the generator once stray energy is detected. InsuloScan (Medline Industries Inc, Mundelein, IL, USA) tests the integrity of the insulating coat prior to the start of the procedure. Vigilant surveillance of electrosurgical instruments is key to preventing thermal injury. Bipolar current has low amplitude and voltage with a continuous waveform. Only the tissue grasped is cauterized because the current is restricted to between the instrument tips that are in contact with the tissue.

The LigaSure vessel-sealing system (Valleylab, Boulder, CO, USA) consists of a grasper connected to a radiofrequency generator. The electrical generator delivers a continuous low-voltage waveform with high-current flow. When a vascular structure is grasped, there is a feedback-response system that subsequently delivers the optimal energy required to seal the vessel. The vessel degrades quickly, causing a protein seal as collagen and elastin fuse because of the high current and low voltage. This mechanism leads to less charring and collateral thermal damage [24]. There is a blade in the jaws to safely divide the obliterated tissue. Vessels up to 7 mm in diameter are effectively sealed with the device [25]. The Gyrus PK Tissue Management System (Gyrus Medical, Minneapolis, MN, USA) is another hemostatic device that uses bipolar energy to seal tissue by melting collagen and elastin. In comparison to the LigaSure system that uses continuous energy, the Gyrus PK uses pulsed energy.

The EnSeal PTC Tissue Sealing and Hemostasis System (SurgRx, Redwood City, CA, USA) also uses bipolar energy, but with a nanotechnology feedback mechanism to reduce thermal spread. The cutting mechanism is in the shape of an "I" beam, utilizing high and equal tissue compression to enhance the seal as the blade is advanced along the length of the jaw. Nanoparticles modulate the current at the tissue–electrode interface as they interrupt the current flow when the temperature exceeds 100° C. Denes *et al*. evaluated the vessel-sealing performance of the EnSeal in a porcine model and reported that the sealed vessel walls of vessels less than 7 mm in diameter are capable of withstanding mean burst pressures greater than 900 mmHg [26]. Clinical studies demonstrated the efficacy of the EnSeal in laparoscopic nephrectomy and radical prostatectomy [27].

Lamberton *et al*. compared various bipolar modalities by measuring the lateral thermal spread, time to seal, burst pressure, and smoke production when used on 5-mm bovine arteries. They authors found that the LigaSure had the highest burst pressure and fastest sealing time; the Harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA), produced the least thermal spread and smoke but had the lowest mean burst pressure; the Gyrus PK had the highest smoke production with variable burst pressures; and the EnSeal was found to be the slowest with variable burst pressures (Table 71.1) [28].

Monopolar radiofrequency

The Endo FB3.0 Floating Ball (Salient Surgical Technologies, Portsmouth, NH, USA) can help in hemostasis of the parenchyma during partial nephrectomy. As a conductive fluid drips from the tip of the device, radiofrequency energy is transmitted through the fluid to the tissue at the point of tissue contact. Collagen in tissues shrinks, stopping blood flow in treated tissues [29]. Fluid is used to increase the contact area and to cool the tissue to prevent charring by keeping the temperature of tissue below 100° C.

Ultrasound

Ultrasound energy is used to achieve precise cutting and coagulation while avoiding the use of monopolar cautery. Electrical energy is transformed into vibration by the use of a piezoelectric crystal system. With the Harmonic scalpel , energy is delivered using a laparoscopic hand-piece with a shaft tuned to conduct the ultrasonic vibration at a rate of 55 000 cycles/s. The vibration produces heat, which is precisely located along the active jaw but the temperature is much lower than with conventional cautery at 50–100° C. This causes cavitation to a short depth of penetration of 1 mm [25]. When the surgeon activates the Harmonic scalpel, tissue is compressed between the jaws, blood vessels are occluded, and vibration causes intracellular vaporization. Proteins are denatured in the tissue and protein coagulum forms to seal the blood vessel while tissue is divided. Water vapor, rather than smoke, is emitted in

Table 71.1 Evaluated parameters for four hemostatic methods (adapted from Lamberton *et al.* [28]).

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the abdomen. Disadvantages of the Harmonic scalpel include its slow action and the need to avoid direct contact with surrounding bowel, as the metallic jaw becomes hot during activation. SonoSurg (Olympus) is a similar device.

Another type of ultrasound device is the cavitational ultrasonic aspirator (CUSA; US Surgical). This device can be used to dissect high water content tissue but it is not used frequently due to the lack of hemostasis and slow action.

Argon gas coagulation

The argon beam coagulator (Conmed, Utica, NY, USA) is useful to treat solid-organ bleeding, such as in the liver, kidney, or spleen. This noncontact system uses a stream of argon gas to improve the delivery of monopolar electrosurgical current; argon is ionized by the current and this makes it more conductive than air. Argon is an inert colorless noncombustible gas that is safe to use with electricity, and it clears the body rapidly. Also, the argon flow improves visualization and coagulation delivery as it disperses blood during coagulation. An insufflation port should be opened during argon coagulation as it can increase the intra-abdominal pressure and lead to gas embolism [30].

Mechanical hemostatic instruments

Temporary vessel occlusion clamps

Instruments that provide temporary occlusion of the renal artery have made laparoscopic partial nephrectomy possible. Endoscopic bulldog clamps are applied through a 10-mm trocar (Figure 71.12). The jaws range between 17 and 45 mm and can be either curved or straight. However, bulldog clamps sometimes do not provide adequate consistent occlusion of the renal vessels and in such cases, such as large or calcified renal arteries, two bulldog clamps can be used. Laparoscopic Satinsky clamps are also available but require an additional 5- or 10-mm flexible trocar or direct percutaneous placement. One drawback of hand-held clamps like the Satinsky clamp is that they may not provide equal distribution of the applied pressure on the blood vessels as they do not follow the contour of the kidney. An *in vitro* study comparing laparoscopic hand-held clamps, such as the Satinsky and DeBakey, to laparoscopic bulldog clamps using a load-cell device showed that the former have stronger occlusive force and that the proximal position of any clamp is associated with the strongest occlusive force [31]. Of note, all vascular clamps, except the silastic rubber vessel loop, were shown to cause endothelial vascular injury in a canine model [32].

The Simon Renal Pole Clamp (Aesculap, Center Valley, PA, USA) is a recently developed instrument that clamps the renal parenchyma to establish regional ischemia in the kidney. The clamp has two wide gently-curved ridged blades and fits a 10-mm trocar. Simon *et al.* reported their successful experience using this instrument in three elective laparoscopic partial nephrectomy cases [33]. The main potential advantage of such a clamp is the maintenance of a bloodless field, while avoiding the risks of hilar dissection and the whole-kidney ischemia of clamping.

Surgical clips

Most clips are made of titanium and are used to occlude small vessels. Clip appliers are mostly single use and multiload with 15–30 clips per load (Table 71.2). The multiloaded single-use applier can save time and decrease blood loss. The diameter of the rotating shaft generally depends on the size of the clips, which ranges from 5 to 11 mm, although there is a 5-mm disposable applier that provides 9-mm clips. Right-angled clip appliers offer better visualization in certain situations when the straight tip cannot be seen (US Surgical).

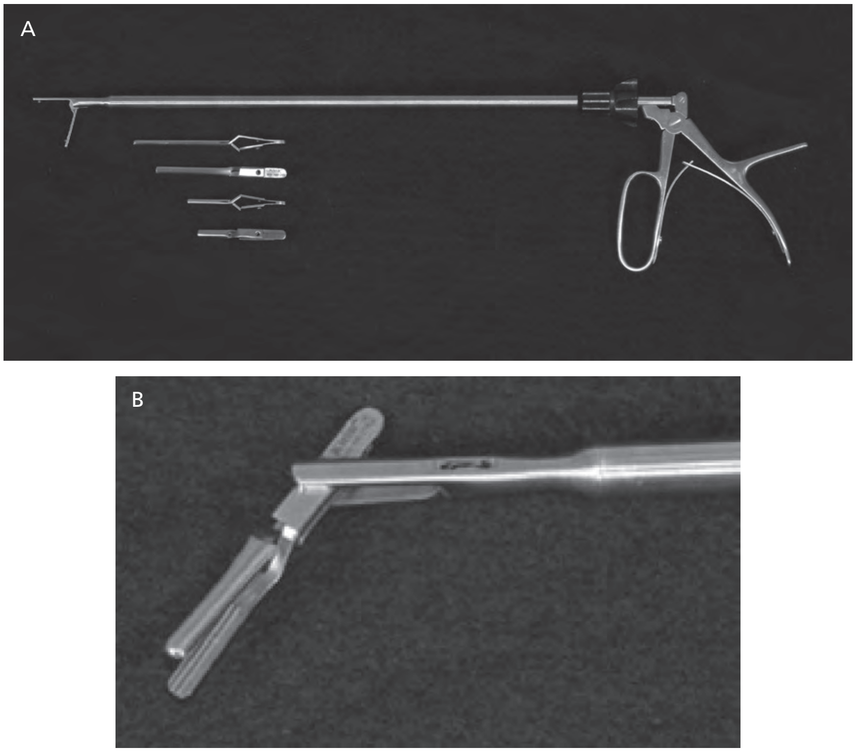

Figure 71.12 (A) This 10-mm applier allows laparoscopic placement of a vascular bulldog clamp. (B) The Klein applier (Klein Surgical Systems, San Antonio, TX, USA) also allows rotation and angulation of the bulldog clamp.

Table 71.2 Clip appliers (multiload, automatic clip loading, single use).

	Endoclip III 5 mm	AcuClip Right-Angle	Endoclip II	Auto Endo 5	Ligaclip Allport	Ligaclip ERCA
Company	US Surgical	US Surgical	US Surgical	Weck	Ethicon	Ethicon
Port size (mm)	5	10	10	5	5	10
Clip material	Titanium	Titanium	Titanium	Polymer (Hem-o-lok)	Titanium	Titanium
Number of clips	18	20	20	15	20	20
Clip size	Medium	Medium/large	Medium/large	Medium/large	Medium/large	Medium/large
Price (US$)*	410	295	330	265	415	258

*Listed prices by retailer prior to any institutional discount.

Hem-o-lok clips (Teleflex Medical, Research Triangle Park, NC, USA) are nonabsorbable radiolucent polymer locking clips. They are available in various sizes to ligate tissue ranging from 5 to 16 mm (Figure 71.13). The Auto Endo 5 (Teleflex Medical) is a new automatic applier preloaded with 15 medium clips. Although absorbable clips exist, there is no evidence of less adhesion formation with their use [34].

Tacking staplers

The laparoscopic biting stapler is useful in refashioning the peritoneum in laparoscopic ureterolysis and fixing mesenteric defects in bowel resections. The staples are made from titanium with sharp ends that enter the tissue and then undergo deformation into a rectangular shape or deploy as a cork-screw to secure the tissue. The most common devices are single use, multiload with 15–30 staples per unit, have a 360° rotating shaft, and may be articulated.

Linear staplers

These devices are essential for rapid and safe intracorporeal tissue division and reapproximation. They release multiple, closely-spaced, parallel rows of titanium staples. There are different color-coded loads: thin or vascular, medium, and large or thick. Depth of tissue penetration of thin staples is around 2.5 mm as they deform to an exaggerated B-shape. These staples are ideal for rapid division of vascular pedicles. Medium-to-large staples are 3.0–4.8 mm thick when closed and are useful in thick tissue such as bowel, bladder, and ureter. Large staples should not be used for hemostasis as they do not fold as tight as thin ones.

Noncutting staplers fire three to four parallel rows of staples, and are useful for closing enterotomies. The Endo TA (US Surgical) is a linear noncutting stapler that is used in laparoscopic donor nephrectomy to provide a longer donor vein as the staples are placed on the donor side only. Cutting staplers deploy loads with six intercalated parallel rows of staples. A knife follows the staples and incises between them, leaving three rows of staples on each side. They are distinguished by the length of the staple line, ranging from 30 to 60 mm, and whether the heads are articulated or not. The Endo GIA Universal linear cutting stapler (US Surgical) is a universal firing device accommodating articulating and nonarticulating loads of various lengths. The ETS-Flex 45 stapler (Ethicon, Somerville, NJ, USA) has similar qualities to the Endo GIA (Table 71.3).

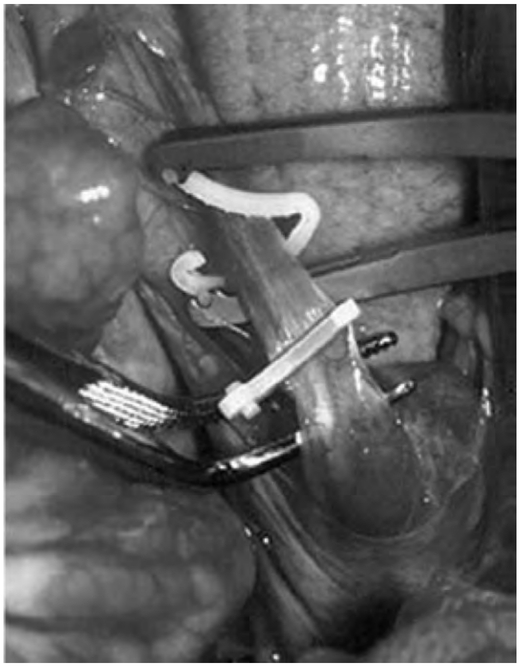

Figure 71.13 Hem-o-lok polymer clips (courtesy of Teleflex Medical, Research Triangle Park, NC, USA).

Loop ligation

Loop ligatures are useful in securing an already transected pedicle. A suture with a preformed sliding, locking knot is passed intracorporally. The structure to be ligated is then passed through the loop with a grasper, and the loop is cinched down with a knot pusher. There are a variety of sutures ranging from plain gut to synthetic absorbable sutures. Port choice is important as the pusher is of fixed length.

Hemostatic agents

Tissue damage activates thrombin from the inactive prothrombin. The activated thrombin cleaves fibrinogen into fibrin monomers that polymerize into fibrin strands that form the actual clot. Coagulation factors have adhesive as well as hemostatic properties. Fibrin in the wound promotes healing by supplying a network for growth of fibroblasts and macrophages [35]. Human thrombin and fibrinogen are applied separately to a bleeding site, resulting in the formation of a layer of fibrin that controls the bleeding and seals tissue. Fibrin tissue adhesive (FTA) is useful in treating complications of laparoscopic surgery, including spleen and liver injury, urinary fistula, and wound dehiscence [36].

Table 71.3 Linear staplers.

	Endo GIA Ultra Universal	Multifire Endo TA 30	Multifire Endo GIA 30	Endopath ETS-Flex	Endopath ETS	Endopath EZ45
Company	US Surgical	US Surgical	US Surgical	Ethicon	Ethicon	Ethicon
Port size (mm)	12	12	12	12	12	18
Staple size (mm)	2, 2.5, 3, 3.5, 4, 4.5, 5	2.5, 3.5	2, 2.5, 3.5	2.5, 3.5, 4.1	2.5, 3.5, 4.1	3.8, 4.5
Staple length (mm)	30, 45, 60	30	30	35, 45	35, 45	45
Rotating shaft	Yes	Yes	Yes	Yes	Yes	Yes
Articulated	Yes (cartridge)	No	No	Yes (device)	No	No
Instrument/reload price (US$)*	350/430	588/263	584/300	680/323	330/323	1008/408

*Listed prices by retailer prior to any institutional discount.

Fibrin agents

Commercial preparations reproduce the final step of coagulation, resulting in adhesive, hemostatic, and healing effects through polymerization of fibrin chains with collagen of adjacent or damaged tissue [37]. The sealants are typically made from a combination of fibrinogen and thrombin with an added fibrinolysis inhibitor that stabilizes the resulting clot. When the fibrinogen and thrombin solutions are mixed, they become active, forming a clot or adhesive. A high thrombin concentration leads to more rapid clot formation, while a higher fibrinogen concentration induces a stronger meshwork. In a laparoscopic porcine heminephrectomy model without any parenchymal suturing, a powder spray formulation of lyophilized fibrinogen and thrombin prevented bleeding and urine leak [38].

Tisseel (Baxter, Glendale, CA, USA) is Food and Drug Administration (FDA) approved for hemostatic and adhesive uses, while CoStasis (Cohesion Technologies Inc, Palo Alto, CA, USA) is approved for hemostasis alone as it uses the patient's own plasma mixed with bovine thrombin and collagen. All fibrin products work best on a dry field in contrast to matrix agents which need the patient's own blood components to be activated. Despite the absence of any reported cases of viral transmission, this concern led to the development of products that use autologous blood to obtain thrombin and fibrinogen, such as Vitagel (Orthovita, Malvern, PA, USA) and CryoSeal (Thermogenesis, Rancho Cordova, CA, USA).

Matrix agents

Matrix hemostats have no adhesive properties but are excellent for hemostasis during active bleeding, as they require a bleeding source of fibrinogen [39]. FloSeal (Baxter, Deerfield, IL, USA) consists of cross-linked bovine collagen granules soaked in human thrombin. Upon contact with blood, the granules swell to provide a tamponade effect. The matrix is biocompatible and is reabsorbed in 8 weeks. Side effects are related to bovine allergy and potential for viral transmission. Another product is the EndoAvitene (Davol, Warwick, RI, USA), which is a preloaded endoscopic system that contains an active collagen that accelerates platelet aggregation and release of fibrin to form clot.

Chemical agents

Chemical sealants, as their name suggests, are used for tissue adhesion and not specifically for hemostasis, although adherence to vessels may physically seal them. BioGlue (CryoLife Inc, Kennesaw, GA, USA) is composed of bovine serum albumin (BSA) and glutaraldehyde. The latter compound cross-links the BSA molecules to the tissue protein, independent of the clotting cascade. Polymerization occurs within 30 s of application and maximal strength is achieved at 2 min. CoSeal (Baxter) is completely synthetic and has immediate capabilities, but must be applied in a dry field as must BioGlue. It is a polyethylene glycol hydrogel and is FDA approved for sealing vascular grafts [40]. Extensive swelling of CoSeal upon activation is a concern when applied in closed spaces.

Complications and limitations

The risks of fibrin products include viral transmission, anaphylaxis, and coagulopathy due to the use of homologous and bovine products. Human immunodeficiency virus (HIV), Epstein–Barr virus (EBV), cytomegalovirus (CMV), and hepatitis viral transmission due to the use of human samples is controlled by donor screening, thrombin nanofiltration, fibrinogen heat pasteurization, and solvent/detergent treatment [41, 42]. Anaphylaxis is rare and there is only one case report of allergy to aprotinin [43]. The use of products containing bovine proteins in patients known to have hypersensitivity to bovine products is contraindicated. There are no reported systemic effects of sealants, which potentially include systemic activation of the coagulation cascade and fatal thrombosis.

There is no perfect agent (Table 71.4). Fibrin products need a long preparation time, which makes them less useful in certain situations such as uncontrolled hemorrhage. Matrix hemostats have limited adhesive properties and need to be administered in a short period of time. Chemical sealants are prepared very fast but they are less absorbable than other components, not as useful for hemostasis, and require a dry field.

Suturing instruments

Difficulties with intracorporeal laparoscopic suturing are due to a fixed center of motion, limited needle and suture handling ability, lack of 3D perspective, and intracorporeal knot tying. Free-hand suturing is applicable to most situations and offers the greatest flexibility in needle, suture, and angle at which a needle may be held. Needle drivers can have a single action or a Castro–Viejo-type inline locking mechanism. Additional instruments have been developed to facilitate suturing.

The Endo Stitch (US Surgical) is an innovative device that passes a small needle with its secured suture back and forth between its jaws, allowing both running and interrupted suturing techniques without reloading the needle and facilitating rapid intracorporeal knot tying. Its limitations include its 10-mm width and short dull needle that cannot pass through thick tissue. As the

Table 71.4 Hemostatic agents and sealants.

Product	Class	Composition	Field	Limitations	Price (US$)*
Tisseel (Baxter)	Fibrin	Allogenic fibrinogen + thrombin Synthetic aprotinin	Dry	Viral transmission Preparation time 20 min	205 (4 mL)
Evicel (Ethicon)	Fibrin	Allogenic fibrinogen + thrombin No fibrinolytic	Dry	Viral transmission	250 (2 mL)
Vitagel (Orthovita)	Fibrin	Autologous plasma fibrinogen Bovine thrombin + collagen	Dry	Bovine allergy Preparation time 7 min	520 (5 mL)
CryoSeal (Thermo-genesis)**	Fibrin	Autologous plasma fibrinogen Autologous plasma thrombin	Dry	Need 400 mL plasma Preparation time 60 min Need intact coagulation	N/A
FloSeal (Baxter)	Matrix	Allogenic thrombin Bovine collagen	Wet	Viral transmission Bovine allergy	180 (5 mL)
Avitene (Davol)	Matrix	Bovine collagen	Wet	Bovine allergy Need intact coagulation	202 1 g)
BioGlue (Cryolife)	Chemical	Bovine serum albumin Glutaraldehyde	Dry	Forms hard matrix Urinary obstruction	662 (5 mL)
CoSeal (Baxter)	Chemical	Polyethylene glycol Hydrogen chloride	Dry	Expansion up to four times	544 (4 mL)

*Listed prices by retailer prior to any institutional discount.
**Cryoseal is not available in the USA.

device is disposable and needs proprietary reloads, it adds to the expenses of the case. The Endo Stitch has been used successfully in reconstructive cases, as in pyeloplasty [44].

The Suture Assist (Ethicon) is a 5-mm instrument designed to quickly place a pretied knot after using either the device or a needle driver to place a single or figure-of-eight throw. It is also disposable and uses dedicated reloads.

The Sew-Right SR5 (LSI Solutions, Rochester, NY, USA) uses two in-built needles to place a simple suture precisely through even relatively thick tissue. Advantages include its 5-mm size and needle passage parallel to the device. If the needle deviates or does not fully penetrate the tissue, it will not engage the suture at the distal jaw. It is disposable and allows only a single simple suture every load.

The Quick-Stitch (Pare Surgical, Englewood, CO, USA) is available in 3-, 5-, 10-, and 12-mm versions. It has a proprietary needle driver passed through a spool containing a pretied knot. A single or figure-of-eight suture is placed, followed by release, setting, and advancement of the knot. The device and needle driver are reusable, making it commercially appealing. Straight, curved, and blunt needles are available on absorbable and nonabsorbable suture.

Intracorporeal knot tying is a quick and versatile technique that may challenge novice laparoscopists. Knot tying is challenging, especially the second knot in a running suture, as there is only a short suture length available for tying, a single strand needs to be tied to a loop, and it is difficult to maintain constant tension on a knot. The Lapra-Ty (Ethicon Endo-Surgery) is an absorbable polydioxanone clip delivered by a reusable 10-mm device. The Lapra-Ty can be placed on the tail of a suture as the first knot or at the end of a running or simple suture instead of tying a knot. A concern is that a large number of clips may incite an inflammatory reaction. Therefore, it is better to use this device for the final "knot" of running sutures.

Another "knot-tying" device is the TiKnot TK5 (LSI Solutions). It is similar to extracorporeal knot tying using a titanium cylinder as a knot. Advantages promoted by the manufacturer include precise tensioning, one-step suture tying and cutting, and titanium's nonreactivity. Disadvantages are the need for extracorporeal loading of the suture into the device and the costs of a disposable instrument.

Tissue entrapment and retrieval instruments

There are various instruments available for tissue entrapment, depending on the size of tissue and whether or not an intact specimen needs to be retrieved. The Endocatch (US Surgical) is a self-opening bag that comes in several sizes, including 10 mm and 15 mm. The

Endopath (Ethicon) is available in the 10-mm size only. Once the instrument is passed into the cavity, the inner core handle slides forward, advancing the bag. A metal band automatically opens the bag and this is used to entrap the specimen. The bag is closed and torn away from the metallic ring when a separate string is pulled. Both bags are not strong enough for morcellation.

Morcellation requires a more robust impermeable bag that does not allow leakage of bacteria or tumor cells [45]. The LapSac (Cook Urological Inc, Spencer, IN, USA) is a double layer of plastic and nylon and is the most resistant to tearing [46]. There are some tricks that allow the bag to entrap large specimens. A stiff-wire is passed through the holes in the LapSac to create a rigid opening. The bag and wire are rolled up and inserted through an 11-mm trocar site after removing the trocar. Then the trocar is passed through the wire to maintain pneumoperitoneum. After the specimen is entrapped, the wire is pulled and the sac is brought out through the trocar site.

Morcellation

Morcellation is needed when there is no involved malignancy and incision is not required. Morcellation of malignant lesions is controversial, if not contraindicated [47, 48]. Morcellation is done after entrapping the specimen in an impermeable bag (see above). After removing the strings of the bag and the trocar, the area is draped to prevent contamination. The simplest and cheapest way is through manual fragmentation and extraction of large pieces using forceps and Kocher clamps, after expanding the fascial incision to about 20 mm. Morcellation should be done under endoscopic vision to verify the integrity of the bag. The use of India ink may help in the determination of margin and staging [49].

Instruments for closure

Port sites that are 10 mm or wider should be closed as the incidence of port-site hernia is as high as 3% [50]. Theoretically, newer dilating noncutting trocars do not require closure up to 12 mm, but many surgeons continue to close sites of 10 mm or wider in adults and of 5 mm in children. Open suture closure can be performed using S-retractors, Alice clamps, and a 0-0 suture, but can be difficult, especially in obese patients. Several instruments have been developed to simplify the procedure of suture passage through the fascia into the cavity under direct vision, followed by suture retrieval with a second pass through the opposite side of the fascia.

The Carter–Thomason Needle-Point Suture Passer (Inlet Medical Inc, Eden Prairie, MN, USA) and Berci Fascial Closure Device (Karl Storz GmbH & Co KG, Tuttlingen, Germany) are very commonly used instruments (Figure 71.14). The Carter–Thomason is now only available for purchase as a disposable instrument (CT Closure System; Cooper Surgical, Trumbull, CT, USA). The EndoClose (US Surgical) is a similar disposable device but is more difficult to use due to its lower rigidity.

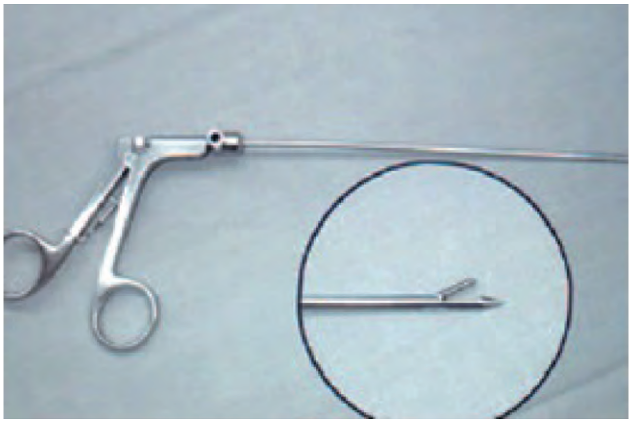

Figure 71.14 Berci fascial closure device (Karl Storz GmbH & Co KG, Tuttlingen, Germany) with tip close-up.

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CHAPTER 72

Robotic Surgery: Basic Instrumentation and Troubleshooting

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The da Vinci System

The da Vinci Surgical System (Intuitive Surgical Inc, Sunnyvale, CA, USA) consists of three core components: a surgeon's console, a vision tower, and a patient cart with robotic arms. One arm controls the camera and the remaining two to three arms manipulate surgical instruments. The instruments have 7 degrees of freedom (DOF), including rotation, allowing for wristed, articulated movement. The surgeon sits at the console and is presented with a high-resolution three-dimensional (3D) view of the surgical field.

Surgeon's console (Figure 72.1)

The console is located in the same room as the patient. The console includes a stereo viewer with sensors as a safety mechanism. The system is activated when the surgeon's head is positioned in the console, and only then are the system arms allowed to move. If the surgeon's head is removed, deactivation occurs, and the robotic arms are locked in place.

The surgeon sits at the console with fingers inserted into two master controllers. The surgeon's hand movements are processed by compute engines and sent to the patient cart, which controls the robotic instruments inside the patient's body in realtime. With computer-assisted surgery, motion scaling can be performed to filter out physiologic tremor, allowing for finer movements [1].

Basic adjustments to the system, such as camera control, scope set-up, audio volume, and console height can be made while the surgeon is seated at the console. The console also allows the surgeon to toggle between the patient cart arms. All these tasks can be accomplished with the console's hand and foot pedal controls. The console is connected to the vision cart and patient cart components via cables.

Optical system

The da Vinci System offers 3D magnified vision. A binocular telescopic camera lens (0° or 30°) is attached to a high-resolution 3D high-definition (HD) camera (if HD System), and together they are held on the central robotic manipulator arm. The binocular images are translated by the computer into a magnified 3D image when viewed at the surgeon's console via the binocular viewport (Figure 72.2) [2]. The robotic scope is 12 mm in diameter and contains two 5-mm scopes. The images are cast on two different cathode ray tube (CRT) (LCD on Si Systems) screens and then synchronized to reflect the images of the CRT (LCD) to the binocular viewer in the console.

Patient cart (robotic arms and instruments; Figures 72.3 and 72.4)

The patient cart, consisting of the robotic arms and instruments, is positioned alongside the patient table [3]. The patient cart has either three or four arms, depending on the configuration of the system. Robotic

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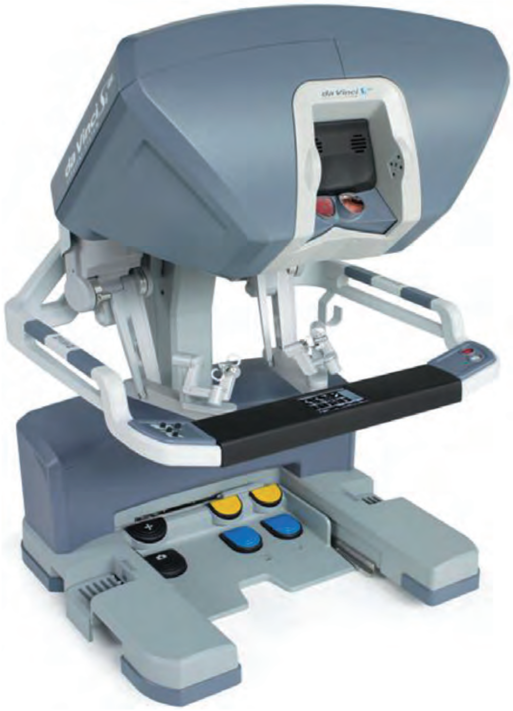

Figure 72.1 Console of the da Vinci Surgical System (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

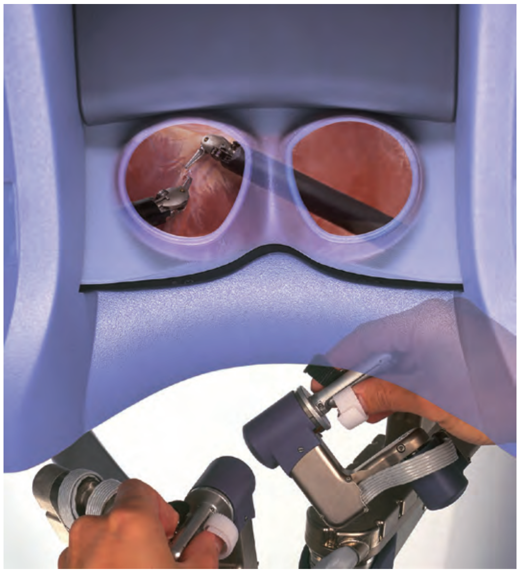

Figure 72.2 Representation of a surgeon's three-dimensional view at the console (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

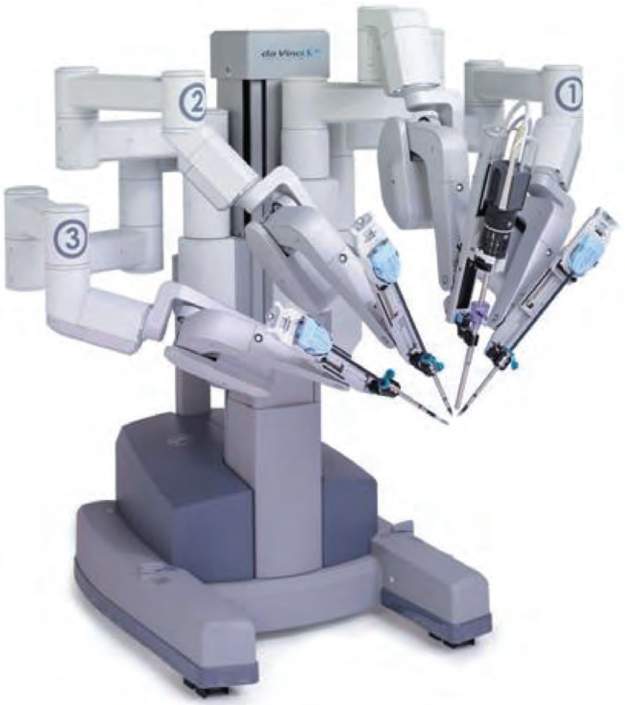

Figure 72.3 Patient cart of the da Vinci Surgical System (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

instruments have articulated joints (EndoWrist) near the tip that allow for wristed movement, providing 7 DOF of movement for surgical tasks such as suturing and dissection. Robotic instruments are available with a variety of instrument tips of 5- or 8-mm diameter.

The EndoWrist instruments are controlled by the surgeon at the console. The surgeon's finger, hand, and arm movements are translated into movements of the instrument tips. The foot pedals are used to toggle between instrument and camera movements, reset instrument movements (clutching), or initiate cautery [2]. If the robotic nondominant instrument is attached to cautery, care must be taken to avoid hitting the wrong foot pedal and causing thermal injury to the bowel or other structures [4].

Different instruments offer different relative advantages for different procedures. Commonly used EndoWrist instruments include: Hot Shears™ monopolar curved scissors, round-tipped scissors, ProGrasp™, fenestrated bipolar grasper, PK™ dissecting forceps, Maryland bipolar forceps, monopolar cautery hook, and needle drivers. In the nondominant hand, the broad smooth tips of the ProGrasp or fenestrated bipolar instruments can be used for atraumatic dissection of vessels. However, the fine sharp tips of the Maryland bipolar forceps or PK dissecting forceps can be used for precise cauterization of small vessels and dissection of structures. The ProGrasp has no thermal energy but has the strongest closing force, making it a robust grasping instrument. In the dominant hand, the Hot Shears can be used for tasks such as cauterization, blunt and sharp dissection, as well as for tumor excision in cases such as robot-assisted partial nephrectomy [4]. The monopolar

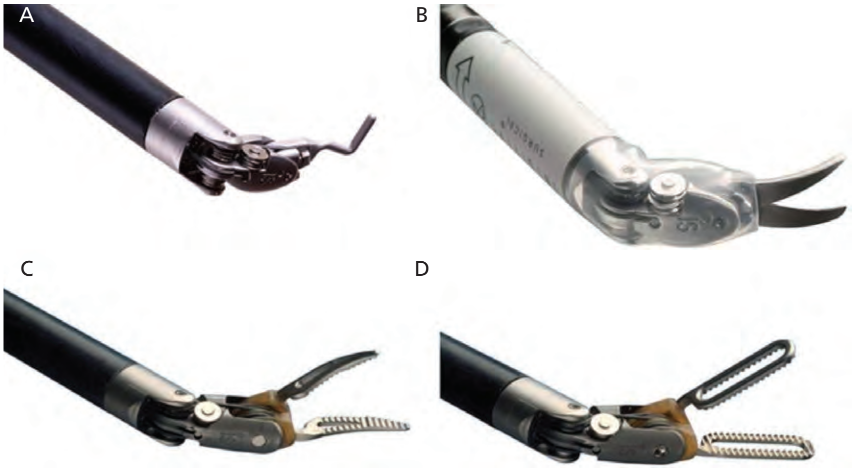

Figure 72.4 EndoWrist instruments. (A) Monopolar hook; (B) monopolar scissors; © Maryland bipolar forceps; (D) Fenestrated bipolar forceps (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

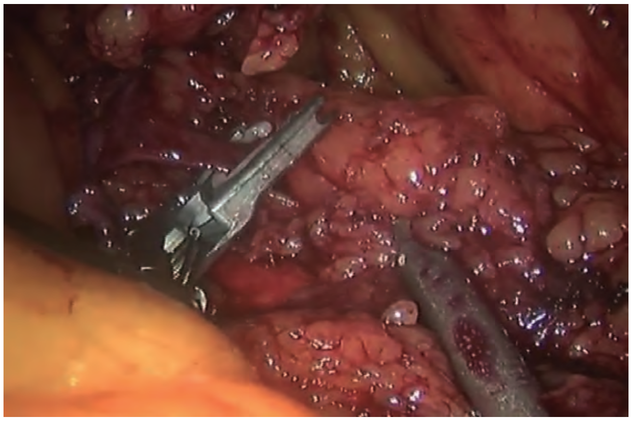

Figure 72.5 EndoWrist Hem-o-lok clip applier (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

hook may be used for blunt dissection of vessels and dissection of tissue planes during extirpative procedures. Robotic ultrasonic shears are available but they lack EndoWrist capability [5].

Robotic needle drivers are available for suturing. The surgeon may choose to use a single EndoWrist needle driver in the dominant hand and keep an EndoWrist grasping instrument in the nondominant hand to economize instrument use. A SutureCut™ needle driver is also available that allows the console surgeon to cut sutures, but the needle tip is more bulky and care must be taken not to accidentally cut the suture while handling it during suturing.

The robotically enabled Hem-o-lok™ clip applier (Figure 72.5) can be useful for clipping vessels, particularly vessels at a challenging angle for the assistant to clip manually. The robotic Hem-o-lok clip applier holds a single 10-mm Hem-o-lok clip that is loaded externally and introduced by the assistant into the robotic port. Having a second robotic Hem-o-lok clip applier can facilitate faster exchanges. Care must be taken not to inadvertently squeeze the fingers as this may cause the clip to misfire. The robotic Hem-o-lok clip applier will accommodate 100 clip firings.

The life of most robotic instruments is 10 cases, after which the system will not allow the operational use of the instrument.

Third instrument arm

The third instrument arm can be utilized to provide retraction independent of the surgical assistant. The third instrument arm port is placed away from the other da Vinci instrument ports to minimize arm collisions. When using the third instrument arm for robot-assisted kidney surgery, a da Vinci S™ or Si™ Surgical System is preferred to avoid external collisions with the patient in the flank position. EndoWrist instruments used with the third instrument arm include the ProGrasp, dual blade retractor, and double fenestrated grasper (Figure 72.6). For robot-assisted kidney surgery, the third instrument arm can be used to lift the kidney anteriorly by placing it under the ureter [6]. This places the renal hilum on stretch, allowing two-handed dissection of hilar vessels. The dual blade retractor is long and has a broad surface area for atraumatic lifting of the kidney. The double fenestrated grasper is also long and may be used to grasp and retract structures. If arm collisions become a problem with the third instrument arm, it may be possible to switch instruments between the third instrument arm and the nearest working arm to minimize collisions.

TilePro multi-image display

TilePro is a multi-image video display mode of the da Vinci S and Si Surgical System that allows the surgeon

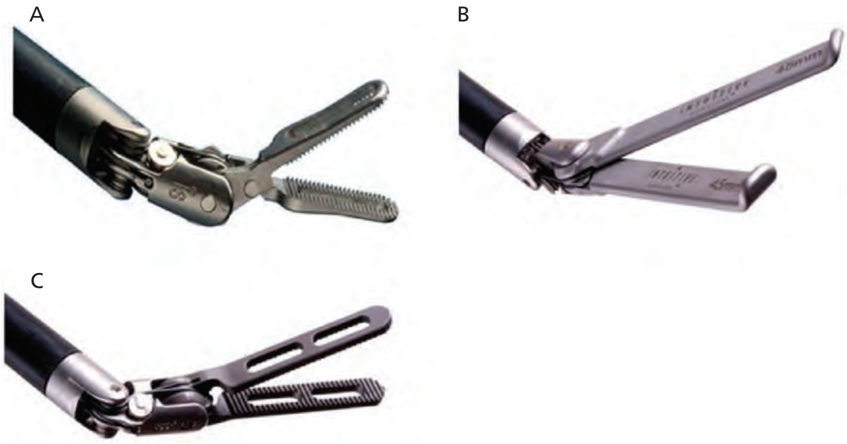

Figure 72.6 EndoWrist instruments with potential third instrument arm application. (A) ProGrasp; (B) dual blade retractor; (C) double fenestrated grasper. (courtesy of Intuitive Surgical Inc, Sunnyvale, CA, USA).

to simultaneously view up to two additional images, such as intraoperative ultrasound and preoperative computed tomography (CT) images, as a picture-on-picture on the 3D console screen and assistant monitors. TilePro can be used during robot-assisted partial nephrectomy to localize tumors and to delineate margins of resection using intraoperative ultrasound without the need to leave the console to view external images [6]. The surgeon can activate and switch back and forth from TilePro mode with a short tap on the camera pedal to turn the images on or off. The size of the image relative to the console view can be adjusted using the surgeon's console control panel. The TilePro images can be viewed on other monitors by the assistant and be recorded by the assistant selecting "Surgeon's view" on the touch screen monitor.

Dual console capability

An optional second console is available with the latest da Vinci Si System and allows two surgeons to collaborate during a procedure. Surgeons can exchange control of the instrument arms and endoscope using the surgeon touchpad, while an in-built intercom system facilitates communication. The addition of a second console offers an environment for training and provides a platform to refine techniques and learn new procedures.

Mechanical failure or malfunction and troubleshooting

Several studies have reported that the incidence of mechanical failure or malfunction with robot-assisted urologic surgery is low (0.4–4.6%) [5, 7–13]. Kim *et al*. reported the incidence of instrument and mechanical failures to be 1.9% [8]. Zorn *et al*. reported four cases of mechanical failure and completed all the cases by delaying the procedures [9]. In the series of Lavery *et al*., 34 cases had mechanical failures or malfunctions and were converted to an open or laparoscopic procedure, or were cancelled [10]. Dry lab experience to allow the surgical team to practice with the robotic instruments and the robotic interface is strongly recommended to learn to prevent and troubleshoot problems [14].

Robotic instrument problems include shaft injuries, broken or dislodged wires, nonrecognition or locking of instruments, or problems with engaging the instrument arm sterile adapter. Instrument failure can be fixed in most cases by reseating the instrument and sterile adaptor or changing to a new instrument. Careful examination of instruments should be undertaken by the table-side surgeon before insertion. If the instrument or sterile adaptor does not engage after replacing the instrument, the sterile adapter is replaced and it is confirmed that all disks spin and are spongy when pressed. If there are still problems with engagement, this should be reported to the Intuitive Surgical dVSTAT group using the Customer Service phone number.

Mechanical failures or malfunctions of the da Vinci System may include on/off failure, malfunctions of the console or optic system, and robotic arm malfunctions. In case of the system not powering on or malfunctions of the console or optic system, all AC power connections and circuit breakers should be checked. System cables should be carefully examined for debris or bent pins and reconnected. If the system is still not powering on or functioning appropriately, the problem should be reported to the Intuitive Surgical dVSTAT group.

If a robotic arm failure occurs, the arm can be disabled by using an option on the surgeon console touchpad and the vision cart touchscreen (da Vinci Si) or pressing and holding the HOME button (da Vinci S). The robotic arm can be moved out of the way by pressing the clutch on the instrument arm.

The da Vinci System will provide warning alarms indicating different faults, which include recoverable and nonrecoverable faults. Examples of recoverable faults include difficulty determining instrument arm position, excessive force on surgical arms, collisions between surgical arms, power fluctuation detected, and low battery back-up. These faults can be overridden by pressing the recover fault button on the surgeon's console touchpad or vision cart touchscreen monitor (Si), or the fault override button (S). If a nonrecoverable fault occurs, the instruments may need to be removed and the system shut down and restarted. Pressing the emergency stop button will stop system operation at any time. This is considered a recoverable fault and can be overridden in a similar fashion.

If a conversion to open or laparoscopic surgery is necessary, instruments and robotic arms from cannulas are manually removed and disconnected using the clutch on the robotic arms. In an emergency conversion, cannulas may be removed with the surgical arms.

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CHAPTER 73

Minimally Invasive Urologic Reconstructive Techniques: Suture, Staple, and Clip Technology

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Introduction

Reconstructive techniques have long been an integral part of urologic surgery. Many common urologic procedures, in fact, rely on surgical reconstruction of the genitourinary system as a major component of the operation. Radical prostatectomy, pyeloplasty, partial nephrectomy, radical and partial cystectomy, ureteral reimplantation, and ureteral reconstructions are examples of common urologic procedures where reconstructive techniques are utilized. The foundations of these techniques lie in open surgery, where principles such as mucosal apposition, tension-free anastomoses, and maintenance of blood supply, have evolved to allow for the success of these surgeries for decades.

With the emergence of minimally invasive and laparoscopic procedures over the past 20 years, challenges arose to duplicate reconstructive techniques in the closed environment. The goal, of course, was to minimize patient morbidity while maintaining success rates. Initially, however, the tools to perform these surgeries were extremely limited, making laparoscopic reconstruction a daunting task for even the most experienced surgeons. The need to perform intracorporeal suturing was the most apparent limitation. However, with perseverance and time, laparoscopic techniques and instruments have evolved to allow these operations to be performed with a high degree of success, with results equivalent to those of open surgery. At the same time, hospital stay, complications, pain medication requirement, recovery period, and return to convalescence have all been markedly reduced [1, 2].

This chapter reviews many of the techniques and instrumentation used in urologic reconstructive laparoscopy. Techniques specific to individual procedures will be covered in the relevant chapters.

Basics of minimally invasive reconstruction

Hemostasis

Hemostasis is essential with any surgery, but it is of particular value when reconstruction is required. Inadequate control of even minimal bleeding can impair proper visualization of the area of interest, a critically important factor necessary for the precise placement of sutures [3]. Suturing in the closed environment is often a time-consuming task and getting things right the first time often gives the best chance for success. As every urologist knows, redoing an anastomosis is both traumatic to the involved tissues and potentially frustrating. Taking the additional time to ensure hemostasis prior to initiating intracorporeal suturing will optimize results.

There are a multitude of methods that can be applied in the laparoscopic environment to achieve hemostatic control, and these fall into several different categories (Table 73.1). First is the application of pressure. This can be achieved with the introduction of a small laparotomy pad into the abdomen for application of local pressure or,

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Table 73.1 Methods for hemostatic control in the laparoscopic environment.

Mechanical pressure
Increasing pressure of pneuomperitoneum
Clamping
Clipping
Stapling
Suture ligation
Thermal energy
Monopolar/bipolar cautery
Argon beam coagulation
Radiofrequency energy
Ultrasonic energy
Chemical adjuvants (see Table 73.2)

if bleeding is more diffuse, the intracorporeal pressure can be briefly increased to aid in hemostatic control. Often, minor venous bleeding may be controlled simply by avoiding manipulation of the bleeding area and temporarily focusing attention on another aspect of the surgical field until physiologic clotting factors have taken effect. Localized bleeding from a distinct vessel may also be controlled with clips, clamps, sutures, or stapling devices. Thermal energy sources are another potential means to control localized bleeding. For example, argon beam coagulation is the initial method of choice to control bleeding arising from a splenic or liver laceration. Monopolar and bipolar cautery instruments are also widely available and may be used to control small vessels. Small vessel bleeding may also be controlled with ultrasonic energy. Suture ligation or repair may be necessary in some instances, such as laceration injuries to larger vascular structures. There is also a wide breadth of products on the market to promote hemostasis in the laparoscopic environment when other measures are inadequate or inappropriate (Table 73.2). If significant bleeding occurs that is not readily amenable to laparoscopic control and repair, open conversion becomes necessary [4].

Skill acquisition

The most important factor when approaching intracorporeal reconstruction is the surgeon's experience. There is no question that laparoscopic needle manipulation and placement, suturing, knot tying, and appropriate tissue handling are some of the most difficult surgical skills to master [5]. The learning curve is long and much of the instrument management can seem counterintuitive. While gaining laparoscopic experience with nonreconstructive techniques such as radical nephrectomy offers crucial skill acquisition in the closed operating environment, it has also been shown that laparoscopic surgical simulators may be helpful in moving up the learning curve more quickly [6–8]. This observation is especially relevant in residency training environments where learning and teaching opportunities are decreasing. Increasing financial and time constraints, pressure due to medicolegal concerns, and limited work hours all contribute to this trend. The importance of developing realistic virtual reality surgical simulators is brought to a new level in this context. While computer simulation in this realm remains limited to date due to difficulty in mimicking the properties of a large range of tissues and their responses to instrument manipulation, even low-fidelity simulators have been shown to offer advantage to surgeons training for laparoscopic surgery. Simple skills such as needle transfer and positioning, suturing, and knot tying can all be practiced and brought to a high level before even stepping into the operating room [9].

Laparoscopic suturing

Developing skill with laparoscopic suturing is probably one of the most daunting challenges in minimally invasive surgery. Frustrations can occur at almost any stage, from introduction of the suture material to the withdrawal of the needle. Seemingly simple tasks that are routine and taken for granted in open surgery, such as needle alignment, may be sources of frustration in the intracorporeal environment. Each step requires a more deliberate approach to avoid frustration and to attain successful results.

Needle passage

The first step in successful application of intracorporeal needle driving is safe introduction of the needle and suture material into the abdominal space through a trocar or directly through the anterior abdominal wall. Experience with a breadth of needle sizes and shapes is helpful in determining which needles can be safely and reliably passed through trocars of different diameters. Additionally, the surgeon must bear in mind that the valve mechanism important for maintaining pneumoperitoneum may be damaged with the passage of a needle. Grasping the suture approximately 1–2 cm proximal to the needle with a laparoscopic needle driver will facilitate passage of both the needle driver and the suture through the trocar, and minimize trauma to the valve by allowing the needle to pass through the path of least resistance. When using a 5-mm trocar with a 5-mm instrument, the internal diameter will not accommodate both a laparoscopic needle driver and needle side by side, and an alternative approach is required. The cut end of the suture is first passed through the trocar and handed off to a second needle driver placed through a second port. The first needle driver may then be withdrawn and the second driver is used to pull the remaining suture and needle through the trocar with the full internal diameter of the trocar available to

Table 73.2 Adjuvant hemostatic agents.

Agent	Product	Manufacturer	Mechanism	Preparation time	Advantages	Disadvantages	Approximate cost (US$)
Oxidized regenerated cellulose	Surgicel Fibrillar Nu-Knit	Johnson & Johnson Ethicon	Matrix for platelet plug formation, vasoconstriction	Off the shelf	Plant-derived Absorbs fluid Bactericidal (acidic environment) Lower cost	Less effective hemostat	12–92/packet
Collagen	Avitene Ultrafoam Instat	Davol Davol Johnson & Johnson	Matrix for platelet plug formation, vasoconstriction	Off the shelf	Plant-derived Available as sponge or powder	Not for use in closed environment Adhesion formation Cost	625/5 mL
Gelatin	Gelfoam Surgifoam	Pfizer/Baxter Johnson & Johnson	Mechanical effect and/or activation of clotting cascade	Off the shelf	Rapid hemostasis May be molded to tissue surface Lower cost	Contraindicated in infected field Risk of embolization	80–120 120
Flowable gelatin/thrombin	Floseal Surgiflo	Baxter Ethicon	Matrix for platelet plug formation, facilitates fibrin clot formation	3–5 min	Rapid hemostasis Precise application More tissue contact than gelatin sponge	Allergic potential (animal-derived thrombin) Cost	262/5 mL
Thrombin (bovine, human, recombinant human)	Thrombin Evithrom Recothrom	King Pharma Johnson & Johnson Zymogenetics	Converts fibrinogen to fibrin Clot stablization	3–5 min	Spray or drip Can be used in combination with gelatin sponges	Animal-derived thrombin may be immunogenic Cost	80/5 mL 95/5 mL 110/5 mL
Fibrin sealants	Tisseel (bovine)	Baxter	Promotes fibrin clot formation and inhibits fibrinolysis	15 min	Suture may be passed through sealant	Higher risk of immune reaction May impair wound healing if applied in thick layers Cost	220/4 mL
	Evicel (human)	Johnson & Johnson		1–3 min	Lower risk of immune reaction Suture may be passed through sealant	May impair wound healing if applied in thick layers Cost	340/4 mL
Synthetic sealants	Bioglue CoSeal	Cryolife Baxter	Binds covalently to tissue surface	1–3 min	Creates shell over applied area	Caution to remove instruments/needles prior to application Cannot suture through Cost	325/5 mL 630/4 mL

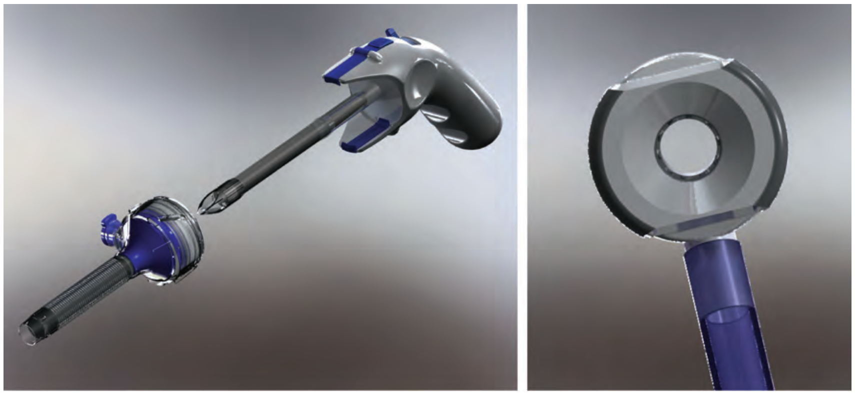

Figure 73.1 Valveless trocar system (SurgiQuest Inc, Orange, CT, USA). The system uses forced air to maintain a focal curtain of high pressure, preventing escape of gas from the abdomen.

accommodate the incoming needle. Direct grasping of the needle for passage is not typically recommended as it fixes the needle in place and may result in undue stress on the trocar valve.

Valveless trocars are now available that can provide advantage in passage of needles, clips, clamps, small specimens, or laparotomy pads in and out of the abdominal space (Figure 73.1). The lack of impedance facilitates passage through the device and, without the presence of a valve, the chances of dislodging a clip or compromising the pneumoperitoneum secondary to valve damage are dramatically reduced.

Straight needles may be passed in an out of the abdomen either through a trocar or directly through the abdominal wall. This technique is particularly useful when a stay suture is needed for placement of temporary traction on a structure during reconstruction (e.g. laparoscopic pyeloplasty). Floppy visceral structures such as the bladder or renal pelvis are examples as they may present a challenge when attempting precise suture placement. Use of a straight needle to place a stay suture in the target viscera can provide exposure and counter-traction. Placement of the suture directly through the abdominal wall, through the target tissue, and then back out through the abdominal wall allows the suture to be clamped outside the abdomen on appropriate traction. This technique may therefore obviate the need for an additional trocar for purposes of retraction, decreasing morbidity and freeing both the surgeon's hands for needle driving and suture tying. Traction can be easily adjusted as needed as the reconstruction proceeds.

Needle driving

Successful needle driving requires both correct needle and tissue alignment. After introducing a suture into the abdomen, two needle drivers are typically used to grasp and align the suture. The assisting instrument (most often the nondominant hand) grasps either the needle itself near the tip or the suture immediately adjacent to the needle. This facilitates needle manipulation until the desired alignment is achieved. When using a curved needle, positioning the driver halfway along the arc of the needle maximizes the level of control. Similarly, when using a straight needle, the positioning of the driver midway along the shaft of a straight needle provides the best level of control. Needle drivers themselves are available in several different configurations and may be used according to surgeon preference (Figure 73.2). Finding the most comfortable driver will often provide an additional level of control and aid in precise needle placement.

Once properly positioned, the assisting instrument helps to provide both proper tissue alignment and counter-traction during passage of the needle. It is important to fully engage the locking mechanism of the laparoscopic needle driver before passing the suture. Taking this step will help minimize unintentional needle deflections and increase the precision with which intracorporeal suturing can be performed. Zooming in with the laparoscope and taking advantage of the magnification it provides will further increase precision of suture placement. After passing the needle through the entrance site, the assisting instrument continues to provide counter-traction while the driver either further advances the needle or grasps it near the tip to complete the bite and exit the needle from the tissue.

Angles of a suture line or tissue position often require the surgeon to place sutures using a backhand technique or to use the nondominant hand for needle driving. It is critical for the surgeon to be comfortable with both of these methods as they can facilitate optimal suture placement and tissue reconstruction when applied appropriately. Also contributing to level of difficulty is the nonstatic nature of abdominal viscera that may move secondary to peristalsis or respiratory excursion.

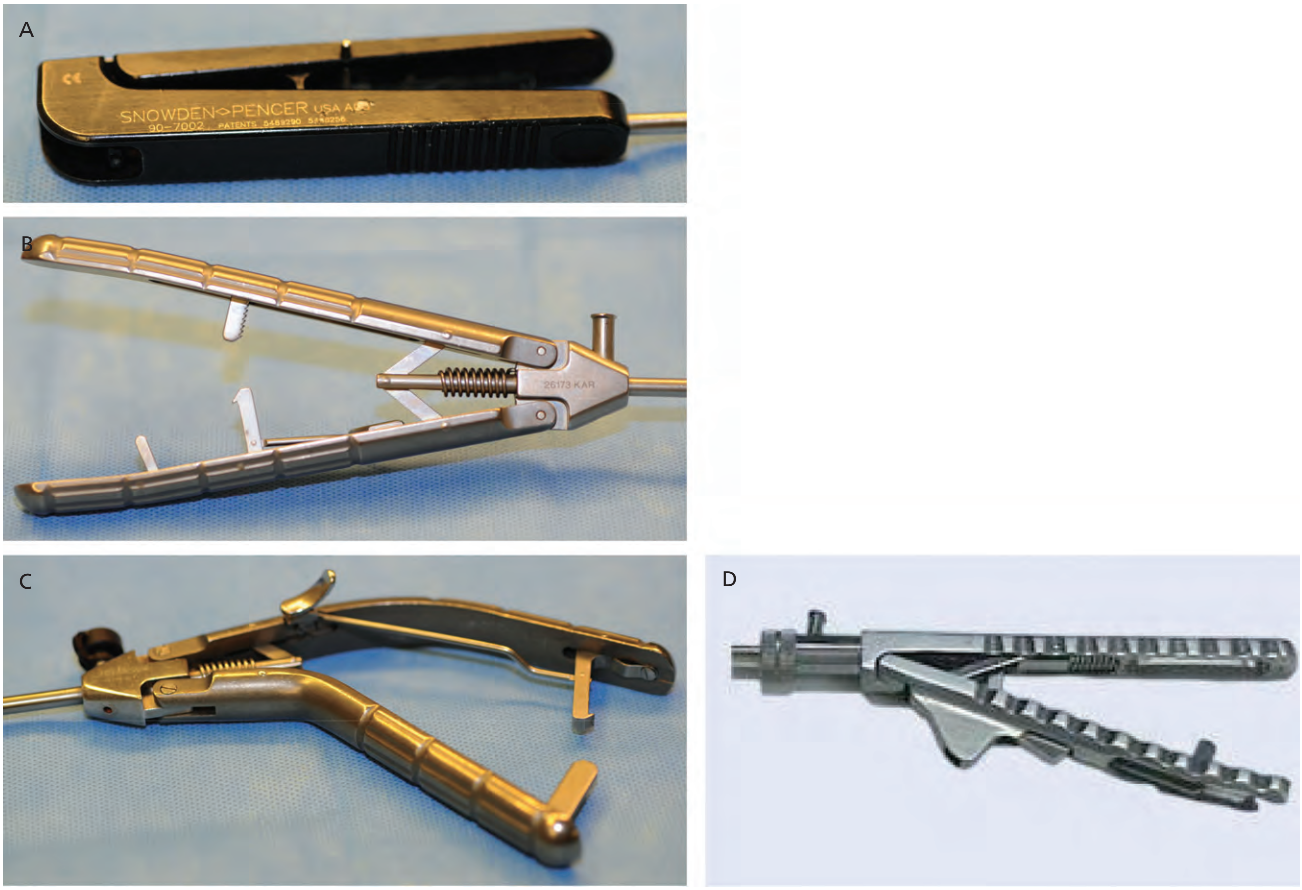

Figure 73.2 Handles available for laparoscopic needle drivers. Each has different locking and unlocking mechanisms. (A) Back-hinged needle driver (Snowder-Pencer Inc, Tucker, GA, USA). (B) Pistol and (C) palm grip needle drivers (Karl Storz, Tuttlingen, Germany). (D) Pistol grip needle driver (Ethicon, Cincinnati, OH, USA).

Methods to stabilize an area targeted for reconstruction include placement of stay sutures (as mentioned above), introduction of a laparotomy pad to bolster tissues, and accessory instruments for retraction.

Suturing

The principles of suture placement apply equally to both open and laparoscopic surgery. The primary goal in reconstructive cases is to achieve bites that equally appose each side of a suture line. Maintaining equal depth of entrance and exit sites on both sides of an anastomosis helps to avoid undue tension on one side or the other and reduces the chance of stricture. Similarly with renorrhaphy after partial nephrectomy, equal spacing and depth of needle entrance and exit sites helps avoid placing asymmetric tension on the kidney when cinching the suture. Undue tension can result in the suture pulling through the renal parenchyma, increasing both the complexity and time of the repair.

Urologic reconstruction utilizes a large breadth of techniques, suture material, size, and length, depending on both the procedure being performed and surgeon preference. The choice is often dictated by tissue thickness and texture. Simple interrupted sutures require the shortest suture length and typically 8–10 cm is adequate [10]. Running sutures require additional length that will vary with size of the defect to be closed or the circumference of the anastomosis. Approximately 10–12 mm of additional suture length is needed for each additional throw of the suture. Running locking sutures require significant additional length, with 20–25 mm needed per stitch. With larger closures, this may result in a cumbersome length of intracorporeal suture that can complicate or prolong the reconstruction. In these cases, separate sutures are recommended to facilitate the process. Adequate length should be maintained for knot tying at the conclusion of suturing such that manipulation of the suture for tying does not place stress on the reconstructed tissue.

An additional method of intracorporeal suturing involves the use of purpose-built instruments that automatically grasp, drive, and regrasp the needle. The Endo Stitch (Autosuture, US Surgical, Norwalk, CT, USA) is such a device that allows for suturing with a single instrument rather than two separate needle drivers. In order to suture, the needle with attached suture is transferred back and forth between the two arms in a side-to-side fashion at the tip of the instrument. After each pass, the needle is temporarily locked in place until the instrument handle is squeezed again to transfer it to the other arm. Its diameter requires a 10-mm port and it is best suited for reconstruction of thin visceral structures, such as the renal pelvis during pyeloplasty or bladder during ureteral reimplant. The small needle size used with the Endo Stitch device prohibits its use for reconstruction requiring larger bites, such as renorrhaphy.

There are also 5-mm instruments available for intracorporeal suturing using a mechanism that passes the suture in a direction parallel to the instrument shaft. The Sew-Right device (LSI Solutions, Victor, NY, USA) incorporates a notch near the tip of the instrument to accommodate the target tissue (Figure 73.3). A needle can then be passed forward through the tissue, locking into the suture at the distal end of the instrument. The suture is then brought back through the tissue to complete the "driving" of the suture. Engaging the handle again will reset the suture at the distal end of the instrument to prepare for the next pass. Once the suture is complete, the instrument is disengaged from the suture and a separate purpose-built instrument is used to pass titanium knots onto the suture, securing it in place.

Knot tying

Suturing in laparoscopic surgery can involve either intracorporeal or extracorporeal techniques. The basic principles broadly overlap and familiarity with each may be useful for various applications.

Extracorporeal techniques

Most commonly, extracorporeal knot tying is used for fascial closure of trocar entry points. There are numerous devices that may be used to assist in suture passage through the fascia from extra- to intra-corporeal space and back under visual guidance from the laparoscope. This technique is particularly useful in obese patients where pure extracorporeal fascial closure can present an extremely difficult challenge without significant enlargement of the skin incision. With a sling suture technique and extracorporeal knotting, the fascia may be closed while preserving the minimally invasive nature of the surgery.

The simplest and most ubiquitous extracorporeal knot is the square knot. This may be used in combination with intracorporeal suturing by maintaining a long suture length (80–120 cm) and using a knot pusher. With

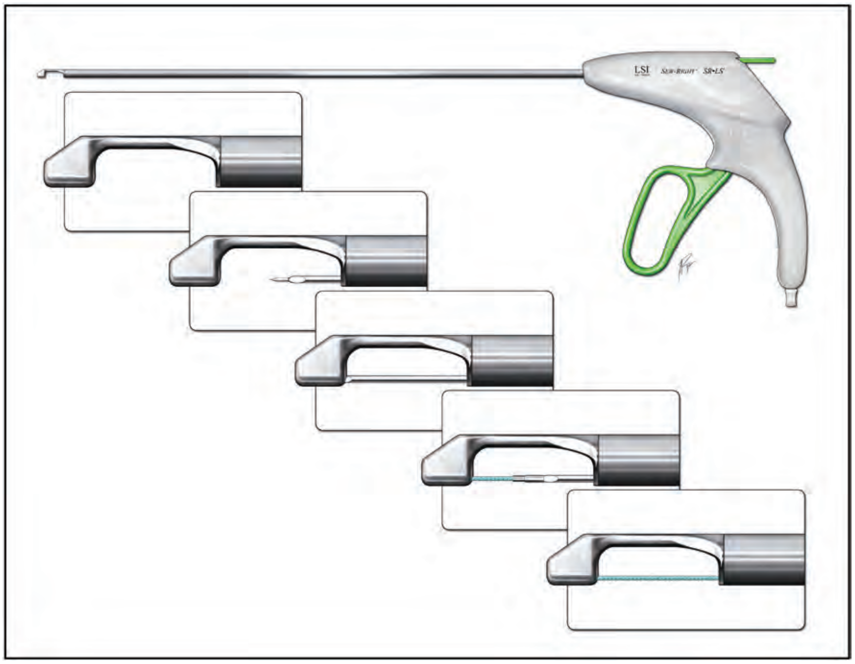

Figure 73.3 Sew-Right device (LSI Solutions, Victor, NY, USA) provides an automatic suture passing mechanism in a direction parallel to the 5-mm instrument shaft (courtesy of LSI Solutions).

the tail of the suture clamped outside of the trocar, the needle may be brought back through the trocar after suture placement in the target tissue. Alternating half hitches may then be formed, with the knot pusher being used to cinch each throw down to the tissue. Placing a surgeon's knot as the first throw will help maintain tension locally at the level of the tissue while the subsequent hitch is formed extracorporeally. Tension is maintained on the free ends of the suture with one hand while advancing the knot pusher with the other.

The Roeder slip knot may also be employed during laparoscopic suturing or loop ligation. It holds the advantage of being entirely formed before advancing it into the intracorporeal space. The slip feature may be particularly useful if the target tissue for ligation is somewhat bulky (e.g. the dorsal venous complex during laparoscopic radical prostatectomy) or if the target tissue is under tension. With a single throw required, the risk of an air knot is minimized. Once the initial knot is in position, additional half hitches may be placed for security. To form the knot, a half hitch is placed approximately 6 inches above the level of the trocar mouth. With the hitch pinched between the thumb and a finger, the free end is then looped around the two strands. The number of loops is dependent on the suture material used; monofilaments require five to seven loops while braided and gut-based sutures require three to five passes. Finally, the knot is completed by passing the free end of the suture between the two strands and cinching tight. Alternatively, the free end may be wrapped around one of the strands and then brought back up through the first loop formed below the half hitch. In either case, a knot pusher is used to advance the knot to the tissue while maintaining tension on the two strands.

The primary disadvantages of extracorporeal suturing include potential loss of pneumoperitoneum through the internal lumen of the knot pusher, lack of continuous control of the suture locally at the tissue level, maintenance of long suture material length, and placement of undue tension on the target tissue while cinching knots.

Intracorporeal techniques

Intracorporeal knot tying can be one of the more time-consuming parts of laparoscopic reconstructive surgery. Multiple factors in the intracorporeal environment can contribute to the level of difficulty. Sutures may stick to abdominal viscera due to water tension, making it difficult to locate a free end after needle passage. In some instances, more than one suture will be placed for reconstruction prior to tying, making it more challenging to locate the correct suture when knotting is initiated. Use of brightly and various colored suture material may aid in knot tying when more than one suture is required.

Similar to the practice of instrument tying in the open environment, it is recommended to leave a relatively short tail prior to tying a knot. A long tail may make it more difficult to locate the terminal end of the suture and will undoubtedly require additional cinching movements to bring the knot down to the target tissue. Furthermore, if placing a running suture, a lengthy tail will unnecessarily reduce suture length and make tying a knot at the opposite end of the suture line potentially more difficult.

The square knot is the most commonly used intracorporeal knot tying technique. It is also extremely useful to learn to convert a square knot to a sliding knot if the target tissue is under any tension. In order to accomplish this task, two half hitches should be placed in the suture, but neither should be cinched down to the tissue. Instead, the free end of the suture should be grasped and placed on tension. This motion will convert the square to a slip knot, and with the free end still on tension, the knots may be pushed into place with the free instrument. Additional half hitches may then be thrown to properly secure the knot.

Aside from its purpose as a needle driver, the Endo Stitch device may also be used in a knot-tying capacity. Using a grasper to hold the free end of the suture, the length of the suture is brought between the jaws of the device. Passing the needle between the jaws, looping the free end of the suture, then passing the needle back to the original jaw will form a half hitch. The process can be repeated to form a square knot.

Suture anchors

As an alternative to knot tying, suture anchors may be used to secure both running or interrupted sutures. When a suture is complete, it is placed on the desired level of tension and an absorbable clip may be placed *in lieu* of a knot using the Lapra-Ty clip applier (Ethicon, Cincinnati, OH, USA). This device requires a 10-mm port and is nondisposable. It can be especially useful if the length of suture left at the end of a suture line is inadequate to easily tie a knot. These suture anchors may also be useful to reduce the time required to complete time-sensitive tasks such as renorrhaphy. By placing a Lapra-Ty clip at the free end of the suture prior to introducing it into the abdominal space, both sides of the suture material may be secured in this manner.

As mentioned above, titanium knots may also be used to secure a suture. This can be accomplished using a purpose-built instrument such as the Ti-Knot device (LSI Solutions). Both ends of the suture must be maintained at a length to allow the instrument to be loaded onto the two suture ends extracorporeally. Once loaded, the device is passed into the intracorporeal space, the desired tension is achieved, and a titanium knot is deployed, which locks the suture in place.

Surgical clips

Laparoscopic clip appliers are readily available and routinely used for many laparoscopic procedures requiring the ligation of small veins, arteries or lymphatics. There are two main categories of clip materials used in the laparoscopic environment: titanium and nonabsorbable polymer (e.g. Hem-o-lok).

Instrumentation and application of titanium clips

Titanium clips are available in both straight and right-angled variations and are typically disposable, multiple load, single-use devices carrying between 15 and 30 clips per instrument. The advantages of these devices lie in their ability to allow for rapid application of multiple clips without the need to pass the instrument in and out of a trocar. This both decreases the time involved in vessel ligation and eliminates the potential for dislodging a clip on pass-through of the trocar valve. Closure of the clips occurs from distal to proximal, which helps prevent the desired vessel from being pushed forward and out of the apposing arms of the engaging clip as the jaws close. The titanium clips themselves are also typically textured along the internal surface with ridges and depressions to decrease the likelihood of becoming dislodged due to either subsequent dissection following ligation or arterial pressure within the ligated vessel.

Titanium clip appliers have several other features to facilitate their use. A rotational capability of 360° allows for ergonomic hand positioning, translating into ease of use and improved accuracy of clip placement. Some clip appliers also reload clips through an automatic mechanism, eliminating a step in the application of multiple clips in rapid succession. Some appliers slide a new clip into position immediately without requiring any action on the part of the surgeon; others require partial closure of the firing handle or have a separate trigger that reloads a clip when depressed. If the clip applier is to be used as a dissecting instrument in any capacity, the surgeon may elect to use an applier without the automatic reload feature to avoid dislodging the loaded clip during dissection. To avoid inadvertently traumatizing a blood vessel or other structure, most clip appliers are equipped with a safety mechanism preventing closure of the jaws unless a clip has been loaded into place. Most appliers now also incorporate a visual indicator to show the operating room staff if the number of remaining clips is low.

Principles of laparoscopic clip application for vessel ligation follow those of open surgery. First, there must be adequate dissection of the target vessel to both isolate it from surrounding structures and to develop space to place clips, leaving a gap between them and allowing for easy division with laparoscopic shears. A right-angled dissector or other dissecting forceps can be useful for this purpose. Once that is completed, the clip applier should be placed around the vessel and then slid up or down the vessel into optimal position before firing. Care should be taken during withdrawal of the applier as the applied clip may be pulled back and out of position if undue traction is inadvertently transferred to the clip. If a clip is misplaced, Maryland or DeBakey forceps may be used to slowly remove it by backing it straight off the clipped vessel or tissue.

Titanium clips may be used to clip vessels of any size, although most commonly they are applied to small-to-moderate sized structures. If a stapler cannot be applied or is not available, multiple titanium clips may be used as an alternative to clip vessels as large as the main renal artery during laparoscopic nephrectomy. The application of between three to five clips on the proximal side of the renal artery is necessary prior to division (Figure 73.4). For smaller vessels, typically one to two clips are used on both the proximal and distal sides of the area to be divided.

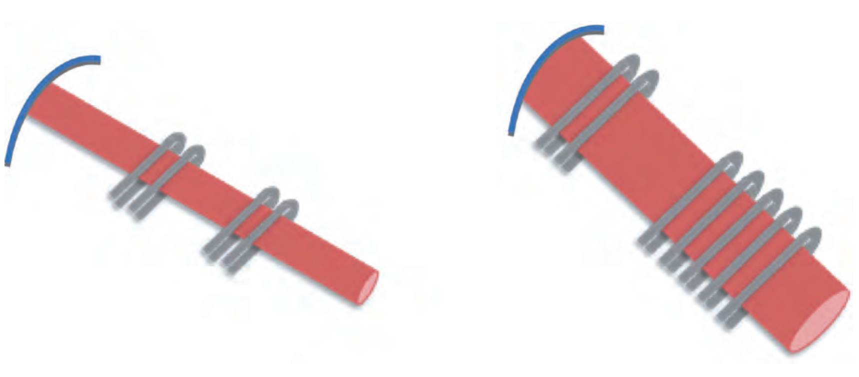

Figure 73.4 Clip ligation of small and large arteries. When using titanium clips to ligate larger vessels, such as the main renal artery, three to five clips should be used on the proximal side prior to division (courtesy of SurgiQuest Inc.).

Nonabsorbable polymer clips

Nonabsorbable polymer clips, more commonly known as Hem-o-lok clips or Weck clips (Weck Teleflex Medical, Research Triangle Park, NC, USA), can also be used for vessel ligation in the laparoscopic environment. These clips incorporate a locking mechanism such that the tips of the two arms can engage and lock through multiple tissue layers. This mechanism provides tactile feedback such that the surgeon can sense if the clip has properly engaged by feeling the transmitted clip closure through the laparoscopic applier. The advantage of this system lies in the security of the clip placement once engaged; they are quite cumbersome to dislodge even when intentionally trying to remove them. Even with the use of a purpose-built Hem-o-lok clip remover that helps disengage the locking mechanism, clip removal can be a challenge. After a clip has been placed and before withdrawing the applier, it is critical to ensure that the clip does not catch on the loading mechanism to avoid placing undue shear force on the target vessel. Similar to the titanium clip appliers, the Hem-o-lok clip appliers also have 360° rotational ability. Because the Hem-o-lok clip appliers are not multiple-load devices, the instrument must be removed and reloaded for each clip application. This occasionally leads to a clip becoming dislodged when passing into a trocar or through the abdominal cavity.

Linear surgical staplers

Laparoscopic stapling devices can be used for a multitude of purposes. In urologic procedures, they are primarily used for vessel ligation and division or reapproximation of visceral structures. They allow for rapid ligation with or without division of tissues by deploying several parallel rows of metallic staples laid in a brick-like intercalated pattern to allow overlap from one row to the next. Cutting devices typically use two sets of three parallel rows of staples and divide the ligated tissue between them. Noncutting staplers use fewer rows (three or four) of staples. Different lengths (30, 45, and 60 mm) and load types (vascular or thin loads, medium, and large) are also available (Figure 73.5). As their name suggests, vascular loads are ideal for ligation of vascular pedicles, such as the renal hilum during nephrectomy or bladder pedicles during cystectomy. The medium and large loads are useful for securing thicker structures such as bladder or bowel. All staplers offer 360° rotation and many are available with either a straight or articulating head. The articulating head can offer a greater range of motion and diversity in angle of application from a fixed trocar site. The downside is that articulating staplers come at a higher cost.

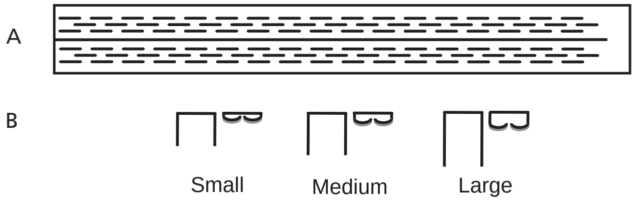

Figure 73.5 (A) Linear cutting stapler load showing configuration on the intercalated staples in two sets of three rows. After the stapler is fired, a blade cuts between the two sets of staples to divide the ligated tissue. (B) Individual staples of various sizes shown in both the open and closed position.

Before using a laparoscopic stapling device, several factors must be taken into consideration. First, most staplers require a 12-mm port size in order to be safely passed into the abdomen, and the jaws should be closed when introducing and withdrawing the instrument. This prevents inadvertent trocar dislodgement while passing the instrument. To avoid premature deployment of the staples or cutting blade, all stapling devices incorporate a safety mechanism that must be disengaged prior to firing. The target tissue must also be appropriately dissected free of surrounding connective tissue, of suitable thickness, and accessible to allow the arms of the staplers to be placed accurately, with tips visible, and closed without requiring undue pressure. If the target pedicle is too thick and the jaws do not close easily, there is a risk of incomplete ligation and subsequent bleeding. Reports of stapler misfire have appeared in the literature with a malfunction incidence of approximately 1.7% [11]. However, many of these complications were attributed to misuse of the device rather than equipment failure. The surgeon must always be prepared for this rare complication to avoid excessive blood loss or conversion to an open surgical approach. To minimize the risk of stapler misfire, some groups advocate the use of a noncutting stapler such as the endoscopic TA device. Once vessel ligation is verified, the target pedicle can then be divided. While this approach adds an additional step, it adds very little time to the overall operation. When using a stapler, it is also very important not to place any torque on the device as it is being fired. Doing so may result in either incomplete ligation or avulsion of the target vessel as the staples are fired. After firing the device, the jaws should be reopened prior to withdrawing the device from the target area, and the staple line can be inspected to ensure an intact ligation and hemostasis. In some instances, an additional reload may be required to complete the pedicle ligation. The jaws of the reload may be closed to incorporate and overlap the original staple line if necessary without compromising the ability of the device to fire and cut. However, it is critical to avoid inclusion of a previously placed titanium clip into the jaws of the stapler as this will compromise both the staple deployment and cutting mechanism. Minimizing the number of clips in an area where the use of a laparoscopic stapler can be anticipated (such as the renal hilum) will lessen the chance of encountering difficulty with clips when maneuvering the stapler into position.

Future directions

The tools for laparoscopic reconstruction have improved dramatically over the past 20 years and will surely continue to become increasingly ergonomic and refined with time. While robotic surgery has introduced wristed instruments into the minimally invasive arena, these tools are also beginning to be used more frequently in the pure laparoscopic environment. Single-site surgery has demonstrated the potential of intracorporeal triangulation and may be another step on the path toward further reduction of surgical morbidity. Improving articulating instrumentation will undoubtedly continue to expand the realm of what is feasible, reproducible, and accessible in the laparoscopic environment.

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CHAPTER 74

Obtaining Access: Transperitoneal Approach and Trocar Placement

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Introduction

Laparoscopic urologic surgery has evolved from an academic practice in the 1990s to one which transcends all forms of urologic practice. All successful urologic laparoscopy starts with the establishment of pneumoperitoneum, followed by primary and secondary trocar placement. Number, size, and arrangement of secondary trocars depend on the type of procedure, patient's body habitus, previous surgical procedures, and the surgeon's individual preference. This chapter will address techniques for both closed and open peritoneal access, anterior abdominal wall anatomy, general considerations, technique, and rationale for secondary trocar configuration and complications.

Anterior abdominal wall anatomy

A thorough knowledge of the anterior abdominal wall anatomy is essential for secondary trocar placement. This will decrease the possibility of vascular injury, hernia formation, or loss of access. The abdominal wall muscles are organized into two separate groups: anterolateral and posterior. The quadratus lumborum is the sole muscle in the posterior group [1]. The anterolateral group of abdominal muscles is divided into two subgroups based on the orientation of the muscle fibers. The rectus abdominis and pyramidalis are the two vertical muscles of the anterolateral abdominal group. The external abdominal oblique, internal abdominal oblique, and transversus abdominis muscles are three thin muscular layers that alternate in their fiber direction. The linea alba is a midline fusion of the aponeurosis of both the external and internal oblique that runs from the xiphoid process to the symphysis pubis. The linea alba is devoid of muscle and is ideal for placement of the primary and secondary trocars.

Blood vessels of the anterolateral abdominal wall that can affect laparoscopic port placement are divided into two groups: superficial or cutaneous and deep [1]. Superficial vessels include the superficial epigastric vessels (Figure 74.1). The superficial epigastric artery originates from the femoral artery just below the inguinal ligament. This artery traverses the femoral sheath to course toward the umbilicus in the subcutaneous tissue. Avoidance of these vessels and their branches is possible by transilluminating the abdominal wall.

The deep anterolateral abdominal wall vessels that influence laparoscopic port placement include: the superior and inferior epigastric vessels, intercostal vessels, subcostal vessels, and ascending branch of the deep circumflex iliac vessels [1] (Figure 74.2). The superior epigastric artery is the termination of the internal thoracic artery and courses downward posterior to the rectus abdominis muscle in the rectus sheath. The inferior epigastric artery originates from the external iliac artery just medial to the deep inguinal ring (lateral to the medial umbilical ligament). The inferior epigastric vessel courses toward the umbilicus and traverses the transversalis fascia at the arcuate line to ascend in the rectus sheath posterior to the rectus muscle. Both the superior and inferior epigastric vessels anastomose near

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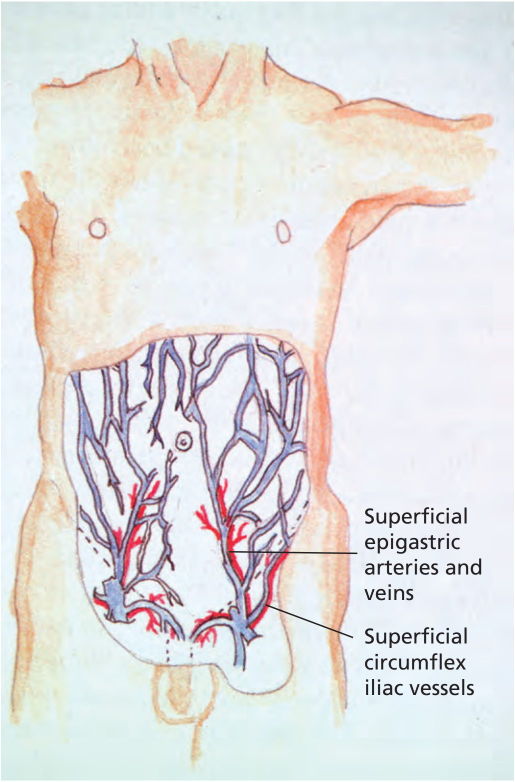
Superficial epigastric arteries and veins
Superficial circumflex iliac vessels

Figure 74.1 Superficial (cutaneous) vessels of the anterolateral abdominal wall.

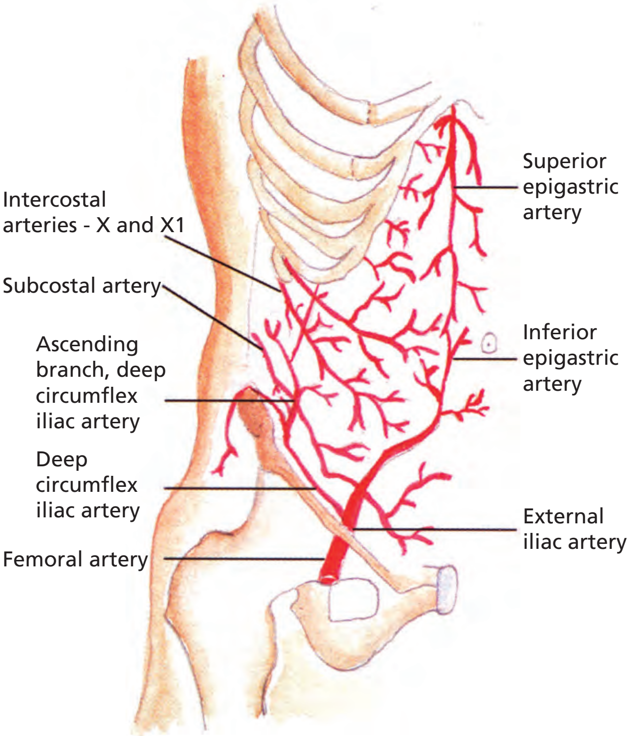
Intercostal arteries - X and X1
Subcostal artery
Ascending branch, deep circumflex iliac artery
Deep circumflex iliac artery
Femoral artery
Superior epigastric artery
Inferior epigastric artery
External iliac artery

Figure 74.2 Deep arteries of the anterolateral abdominal wall.

the umbilicus. Both vessels supply numerous branches to the rectus muscle and umbilicus. These vessels are often not seen on transillumination of the abdominal wall and for this reason, trocar placement through the rectus abdominis muscle should be avoided.

Intercostal vessels (X and XI) and the subcostal vessels traverse the lateral abdominal muscles, coursing in an oblique diagonal fashion from lateral to medial (midline) [1] (Figure 74.2). The ascending branch of the deep circumflex iliac artery originates near the anterior superior spine and ascends toward the costal margin. These vessels are generally not visualized during transillumination of the abdominal wall.

General considerations

While ablative laparoscopic urologic procedures have led the way in the development of minimally invasive urologic procedures, reconstructive urologic procedures are currently mainstream. Most reconstructive procedures are technically more difficult due to the laparoscopic suturing. While few studies exist on standardization of laparoscopic intracorporeal suturing and knot-tying techniques, it is known is that the positioning or placement of the ports plays a crucial role.

Trocar configuration and placement should be well thought out ahead of the procedure to maximize the utility of each individual cannula. Several basic tenets for trocar placement are useful.

Trocars should be placed within the operative field so that the sheath is pointing toward the operative field. Placing the ports in such a manner minimizes resistance when manipulating instruments. Placement of cannulas pointing away from the area of dissection can result in decreased maneuverability and tactile feedback transmitted through the instruments. The force needed to redirect the sheath can cause a tear in the peritonotomy and result in subcutaneous air. Subcutaneous air leads to leakage of gas at the port site, difficulty keeping the trocar in place, and increased gas absorption. The former events turn a simple laparoscopic case into a major struggle.

Another known fact is that secondary trocars must be adequately spaced so that external interlocking of laparoscopic instrument handles and internal overlapping of cannulas and laparoscopic instruments will not hamper surgeon maneuverability. For the novice, prior to secondary trocar placement, individual trocar sites can be mapped with a surgical marker pen after insufflation to ensure adequate working distance between the trocars.

If anterior abdominal trocars are to be used, they should be placed in either the midline or lateral to the rectus muscle to avoid the epigastric vessels and branches. In addition, trocars should be placed away from bony structures since these limit mobility. When the planned procedure requires a dorsal lithotomy or split frog-leg position, lower, laterally placed trocars may pose difficulties. Placement of a secondary trocar at the midline suprapubic area will allow greater trocar movement in these specific cases.

Frede *et al.* have described other special considerations given to secondary trocar configurations for laparoscopic reconstructive procedures in which laparoscopic suturing is needed [2]. They discuss three general rules to optimize laparoscopic suturing. First and foremost, rule 1is that "an isosceles triangle trocar instrument arrangement is needed for optimal suturing." Rule 2 dictates that the angle between laparoscopic instruments be adjusted between 25° and 45°. Rule 3 states that the angle between the horizontal plane and instruments should be kept at less than 55°. According to the authors, by using the above general principals, suturing time was decreased by 75% [2].

Choice of trocar size will vary depending on the size of instruments needed to perform the desired procedure. Routinely used trocars vary in width from 5 to 12 mm. Larger trocars are available for insertion of larger instruments (i.e. specialized bowel/vascular staplers and larger entrapment devices) and passage of suture material. In most instances, one of the secondary trocars should be a 10/12-mm cannula to accommodate larger instruments (clip applicators, tissue removal forceps, etc.). The standard trocar length is 10 cm; extra-long trocars (15 cm) are often used in obese patients. For flank/renal laparoscopic procedures in the obese patient, the whole trocar configuration is moved laterally to assure that laparoscopic instruments will be long enough to reach the field.

Access to the peritoneal cavity

The initial step of laparoscopy is to establish a pneumoperitoneum via an open or closed technique. In inexperienced hands, relative contraindications to pneumoperitoneum are prior abdominal surgery, nonreversible coagulopathy, and severe cardiopulmonary disease. However, several series of transperitoneal laparoscopic procedures in patients with prior surgical procedures have been successfully performed [3].

The closed technique for initiating a pneumoperitoneum is most commonly obtained via direct infusion of CO_2 into the peritoneal cavity through a Veress access needle. The Veress needle (Covidien, Norwalk, CT, USA) is a 14G needle which comes in standard and baratric lengths (Figure 74.3). This needle is made up of an internal spring-loaded blunt-tip stylet surrounded by a sharper outer needle. This design protects intra-abdominal structures via the advancement of the inner sheath after the outer stealth encounters an area of decreased resistance (peritoneal cavity). The most common insufflation site is the umbilicus for pelvic cases and the mid-clavicular line for renal case. The primary advantage of the umbilical route for establishing pneumoperitoneum is the absence of intra-abdominal muscle at this site, so that the needle passes directly through the fused anterior and posterior rectus sheaths. Pneumoperitoneum for renal/adrenal procedures is initiated in the mid-clavicular line above the level of the anterior superior iliac crest. The Veress needle is inserted perpendicular to the fascial surface and the abdominal wall is tented upward with the nondominant hand. Two areas of maximum resistance are encountered as the needle passes through the abdominal wall fascia layers. Tactile feedback is key as the Veress needle passes into the peritoneal cavity (feeling the "two pops" are standard teaching points). Needle advancement is stopped. Correct placement of the needle into the peritoneal cavity is verified by the three tests [3]:

- No resistance when moving the needle tip;
- Saline irrigation and aspiration ("drop test") is preformed without entericus, blood, or air on gentle aspiration;
- Low opening pressures (<8 mmHg) at low flow rates.

It should be noted that obese patients will have higher opening pressures (close to 10 mmHg) secondary to the increased thickness of the abdominal wall and chest wall fat. Due to the extra weight on the abdominal/chest wall, the intra-abdominal pressure will stay at this level until the abdominal cavity reaches capacity (4–6 L).

Occasionally, when the above signs cannot be adequately demonstrated, the surgeon needs to troubleshoot. If the abdominal wall does not demonstrate symmetrical rise, either preperitoneal insufflation is taking place or abdominal hollow structures (i.e. colon or small bowel) are being insufflated. If the latter is suspected, the initial Veress needle should be left and another Veress needle should be placed in a different area. Once access has been obtained and the initial trocar is placed, the initial Veress needle is inspected under direct vision. If it is placed in a hollow viscus, it is at this time removed and necessary repairs are made. Another problem encountered is omental or mesentry insuffla-

Image not available in the electronic edition

Figure 74.3 Veress needle is utilized for closed intraperitoneal access. (Copyright © 2010 Covidien. All rights reserved. Used with the permission of Covidien.)

Image not available in the electronic edition

Figure 74.4 Mesh-like expandable sleeve of the VersaStep Trocar System is back-loaded over a Veress insufflation needle and introduced into the peritoneal cavity in standard fashion. (Copyright © 2010 Covidien. All rights reserved. Used with the permission of Covidien.)

Image not available in the electronic edition

Figure 74.5 Hasson trocar is used to obtain open intraperitoneal access. (Copyright © 2010 Covidien. All rights reserved. Used with the permission of Covidien.)

tions. In this case placement testing appears normal; however, intra-abdominal pressures appear abnormally high or the occlusion alarm sounds. If suspected, the needle should be slowly pulled back and the tip angled upward while keeping an eye on the intra-abdominal pressure after each movement. If pressures do not drop below 8 mmHg, the Veress needle should be withdrawn and reinserted.

With successful establishment of the pneumoperitoneum, the intra-abdominal pressure is increased to 15–20 mmHg. Initial trocar placement is performed with two different techniques: utilizing a blind or visual trocar system. When a blind technique is utilized, either a fascial cutting or fascial splitting trocar is inserted through the abdominal wall with a twisting motion. Alternatively, the initial trocar can be placed via a radially expanding trocar system, which requires the use of a Veress needle which is back loaded with an expandable mesh sleeve prior to insertion. The dilating trocar is placed intra-abdominally by removing the Veress needle but leaving the mesh in place. A blunt-tipped trocar is placed through the mesh with the dominant hand while holding the mesh with the nondominant hand (Figure 74.4). Intraperitoneal trocar placement is confirmed by leakage of CO_2 out of the open side port. Direct videoendoscopic inspection is then preformed to verify intraperitoneal trocar placement and to exclude injury to intraperitoneal structures. Initial closed blind trocar placement is associated with increased risk of injury to intra-abdominal structures when compared to closed visual or open trocar placement [3–5].

Open trocar placement is potentially a safer way of gaining intraperitoneal access in patients with increased risk of intra-abdominal adhesions and scarring. The risk and severity of adhesions is much higher for prior open procedures when compared to the same laparoscopic procedure (66% vs 10%) and for patients with a history of gross spillage of bowel contents and foreign bodies (talc, shunts, peritoneal dialysis catheter, etc.) [3]. However, many experienced laparoscopist have obtained initial access via closed technique and have subsequently performed transperitoneal procedures in these patients [3].

Open (Hasson) technique

The technique to obtain open access for intraperitoneal insufflation is performed by making a 2-cm incision at the desired initial trocar site. With blunt dissection the anterior fascia is exposed with narrow retractors. The anterior fascial layer is incised and stay sutures of 2-0 Vicryl (polyglactin) are placed on either side of the fascia with the aid of a semi-circular needle (UR-5 or UR-6). The underlying structures are bluntly dissected to expose the posterior fascial layer, which is also incised, and the above stay sutures are placed on each side. The peritoneum is exposed, tented up, and incised. A blunt-tipped trocar (Hasson) is placed through the peritoneotomy and the stay sutures secured to the suture guides, holding the cannula in place via an attached circular cuff that prevents leakage of CO_2 (Figure 74.5). Alternatively, a cannula can be back-loaded on a 0° laparoscopic lens to "look your way into the peritoneal cavity." This modification allows the surgeon to immediately confirm correct placement. The open technique's major draw back is leakage of the pneumoperitoneum around the initial trocar. The surgeon should also be aware that this technique is extremely difficult in obese patients.

Hand-assisted access

Hand-assisted laparoscopic surgery requires a primary access site for the hand to assist with videoendoscopic renal surgery. The initial hand-assisted device, Pneumo-Sleeve (Weck Closure Systems, Research Triangle Park, NC, USA) required preinsufflation of the peritoneum for proper placement of the device on the abdominal skin with adhesives. Subsequent hand-assisted devices have inner and outer abdominal rings attached to a wound protector. Pneumoperitoneum is maintained by various modifications of the hand-assisted device: (1) occlusive gel matrix (GelPort; Applied Medical, Rancho Santo Margarita, CA, USA; (2) twisted pneumatic cuff (OmniPort; Weck Closure Systems, Research Triangle Park, NC, USA), and adjustable iris (Lap Disc; Endo-Surgery, Cincinnati, OH, USA). With all of the above hand-assisted devices, the incision for the hand-assisted device can be made first, followed by secondary trocar placement [6].

Laparoendoscopic single-site surgery access

Single port laparoscopic surgery [laparoendoscopic single-site surgery (LESS)] has been introduced into several surgical fields: urology, general surgery, and gynecology. This novel technique consolidates all trocar sites to a single site, usually near the umbilicus. The combination working and laparoscopic lens ports can be inserted by the open (Hasson) approach (Uni-X Single Port Access Laparoscopic System; PNaval Systems, Cleveland, OH, USA) or a closed technique via an introducer after insufflation. The GelPort utilized for hand-assisted laparoscopic surgery can be used in a similar fashion for LESS surgery [7] (Figure 74.6).

Complications of accessing the peritoneal cavity

Complications of transperitoneal access are rare but must be promptly diagnosed and treated. The three main complications areas are vascular injury, bowel injury, and preperitoneal insufflation.

Access injuries related to the abdominal wall vessels and great vessels are a rare occurrence, reported at 0.25% [5]. These significant injuries can be nearly eliminated by the use of direct visual access or open access methods for introduction of the initial port. Diagnosis of access injury is confirmed by the return of large amounts of blood with placement of the Veress needle or initial port. Delayed recognition via laparoscopic lens will demonstrate brisk intraperitoneal bleeding. Laparoscopic management of large vessel bleeding associated with access is generally precluded since secondary working trocars have yet to be placed, thus necessitating rapid open conversion to control bleeding. On the other hand, abdominal wall vessel bleeding that is not brisk will afford secondary trocar placement for control of bleeding. If direct coagulation does not control the abdominal wall vessel, a Carter–Thomason closure device can be used to pass a figure-of-eight absorbable suture to control the bleeding before proceeding with the primary surgery.

Bowel injury during laparoscopic procedures occurs at an incidence of 0.13%. Approximately, one-third of these bowel injuries occur in obtaining initial access [8]. Prevention of access-related bowel injuries includes selecting an entry point furthest away from an abdominal wall scar and/or insufflation at or above the mid-clavicular line when in the flank position. Diagnosis of bowel injury during obtaining access can be suspected with aspiration of succus enterius or with uneven abdominal insufflation. If insufflation of colon or intestine is suspected, it is recommended to leave the Veress needle in place and to obtain peritoneal cavity access via

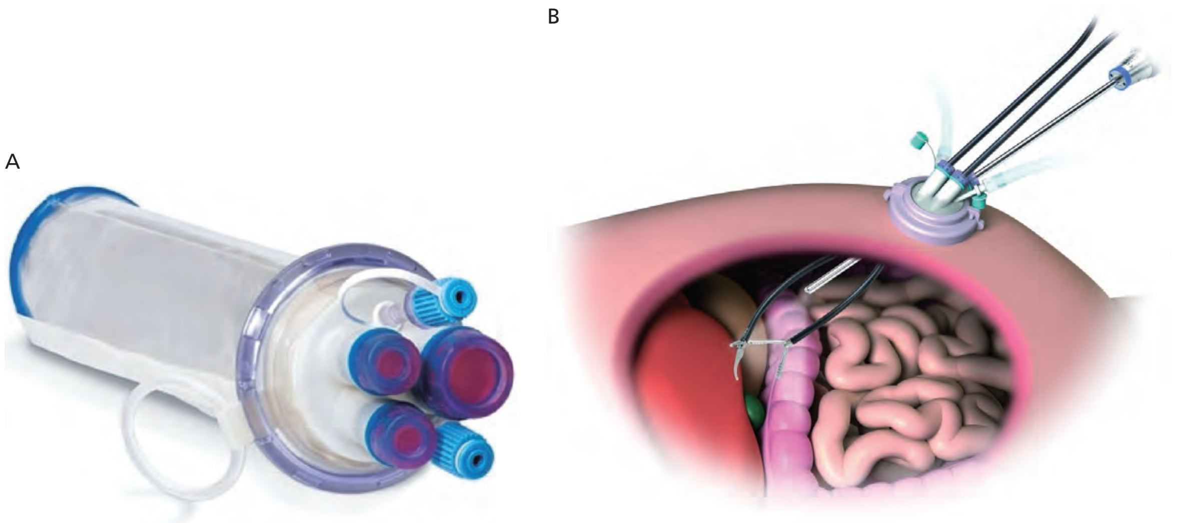

Figure 74.6 (A) Single-site surgery access device made by Olympus (Germany) has access channels for the laparoscopic lens and instruments. (B) Single-site surgery access device in place at the umbilicus, with laparoscope and working instruments in place.

an open technique away from the prior placed Veress needle. If the Veress needle is confirmed to enter into the bowel as an isolated injury, the area of injury can often be repaired via intracorporal laparoscopic suturing techniques. Larger injuries like thermal bowel injuries must be repaired via either laparoscopic or open techniques. If the suspected bowel injury is not found, the bowel has to be completely run.

Seventy percent of bowel injuries are not detected at the time of surgery. Subsequent presenting symptoms can be atypical and include focal trocar tenderness (often without rebound tenderness), leukopenia or diarrhea [8]. Since the delayed presentation of bowel injuries is atypical, a high index of suspicion must be exercised. Diagnosis can be confirmed with serial computed tomography (CT) scan showing increasing intraperitoneal gas [9]. Without early diagnosis and treatment, unrecognized bowel injury after laparoscopic surgery will progress to sepsis, Fornier's gangrene, and eventual death [8].

Preperitoneal insufflation is recognized by high opening pressures (>8–10 mmHg) with initial Veress needle placement coupled with a lower overall volume of insufflation volume compared to intraperitoneal insufflation. Unfortunately, this situation is not confirmed until the laparoscope is introduced into the preperitoneal space, revealing web-like attachments and the confining peritoneum without bowel. With a visual trocar, the peritoneum can be visualized as a collapsed space with intraperitoneal structures within the abdominal cavity. With gentle pressure, the lens can be advanced through the peritoneum.

Secondary trocar technique

After successful creation of the pneumoperitoneum and placement of the initial trocar, secondary trocars are placed under videoendoscopic vision. Prior to trocar placement, the intra-abdominal pressure is increased to 20 mmHg or greater. This increases the rigidity of the anterior wall, providing a stronger platform, which facilitates the downward trocar placement. The room is darkened and the laparoscope is used to transilluminate the anterior abdominal wall. This helps visualize the superficial anterior abdominal wall vessels, which aids in avoiding these structures (Figures 74.1 and 74.2). After the appropriate trocar site is selected, pre-emptive analgesics are injected into the area and a skin incision just large enough to admit the trocar is made along Langer's lines. The subcutaneous tissue is spread with a clamp to push the superficial vessels away from the trocar entry site. The secondary trocar site is checked by pushing downward at the site on the abdominal wall. While watching the interior structures via the camera, the appropriate entry site is recognized by the deformity of the peritoneal surface and is deemed safe or another site is chosen. Again, epigastric or abdominal wall vessels should be avoided.

For the traditional cutting trocar, the technique for placement is as follows. The trocar is held in the palm of the dominant hand with the middle finger extended to act as a brake [10]. If a shielded trocar (a trocar with a safety shield) is used, the shield should be in the set position. The side port stopcock is closed prior to placement. The cannula is placed in the direction of the dissection. However, if two separate operative fields are required, as in a nephrourerterectomy, the trocars are placed perpendicular to the abdominal wall.

All secondary cannulas are placed under laparoscopic monitoring. The incision site is checked to confirm that it is wide enough to accommodate the trocar. An insufficient skin opening can result in excess force being required to enter the peritoneal cavity. Forward pressure is applied using a slow continuous right-to-left twisting motion. The trocar tip is visualized as it enters the abdominal cavity by the deformity of the peritoneum. As the trocar tip comes close to the underlying viscera, it is redirected up and away from the viscera. Once the trocar tip is in the abdominal cavity, the safety shield springs forward. The trocar is advanced further into the abdominal cavity until the sheath is within the peritoneal cavity. The inner obturator is then removed and the sheath is advanced 1–2 cm within the peritoneal cavity.

Once the trocar is placed, it should be fixed in place to prevent accidental removal during dissection. Several manufacturers have integrated retentive grooves into the sheath or made detachable retentive grooves to prevent movement of the trocar sheath. In contrast to integrated grooves, the internal mesh of dilating trocars will function to prevent inadvertent trocar removal. Trocars can also be secured by placing a suture through the skin and tying the suture to the sidearm port. This suture prevents the trocar from being pulled out of the abdominal cavity, while allowing the operator to advance the trocar further into the peritoneal cavity. Radial dilating secondary trocars, VersaStep (Covidien), are placed under direct vision. A skin incision is made to admit the desired trocar size. The expandible mesh sleeve is back-loaded onto a 14G Veress needle. With no dissection of the subcutaneous tissue, this apparatus is passed through the abdominal wall under direct vision.

The inner Veress needle is removed, and a blunt-tipped fascial dilator is back-loaded with its corresponding cannula through a sleeve. It is critical to hold counter-traction with the nondominant hand while passing the dilator/cannula with the dominant hand (Figure 74.4). This step is facilitated by using a constant right-to-left twisting downward pressure. Care is taken to prevent inadvertant injury to intra-abdominal organs. Once the canula has been passed through the abdominal wall, the obturator is removed and the canula depth is adjusted. No stay suture is needed to secure the radial dilating trocars. The fascial defect is reported to be one-half of that of the traditional cutting trocar and thus, there are fewer entry complications, gas leakage, trocar site bleeding, and hernia formation [10–13]. In addition, these studies have demonstrated less postoperative pain at the trocar site with the radial dilating trocars versus the tradition cutting trocars [10–13].

Primary trocar site inspection

After the initial secondary trocar has been placed, a laparoscope is passed through this cannula. The primary trocar site is inspected at its entry point into the peritoneal cavity [3]. If any abdominal viscera (omentum, bowel, etc.) have been traversed, appropriate reparative actions must be initiated. This is also the optimal time to secure the primary trocar to the abdominal wall. Additional secondary trocars are placed as outlined above.

Secondary trocar configuration

Selection of trocar size and secondary trocar arrangement depend on the type of procedure and the surgeon's individual preference. Individual surgeons may choose different trocar configurations based on the patient's body habitus, surgical approach (transperitoneal vs extraperitoneal), and availability of specialized instruments. This section will give some basic secondary trocar arrangements for specific urologic procedures.

Laparoscopic pelvic procedures

Laparoscopic urologic pelvic procedures are performed with two different types of trocar arrangements: a fan or diamond array [2, 14–18]. Procedures utilizing the fan or diamond configurations include pelvic lymphadenectomy, bladder neck suspension, and radical prostatectomy.

In both of these trocar configurations at least two 10/12-mm trocars are needed. One 10/12-mm port is used for the camera and the other port is used for passage of suture material or to remove tissue. The fan configuration is advantageous because this allows use of both hands (Figure 74.7) and has been advocated for use in obese patients. A modified fan configuration (Figure 74.8) was designed for laparoscopic radical prostatectomies. In this configuration the lower trocars are moved from a lateral to a medial or paramedial position. The upper trocars are moved slightly lateral to the midcalvicular line. This rearrangement allows specialized suturing instruments to reach deep into the pelvis where

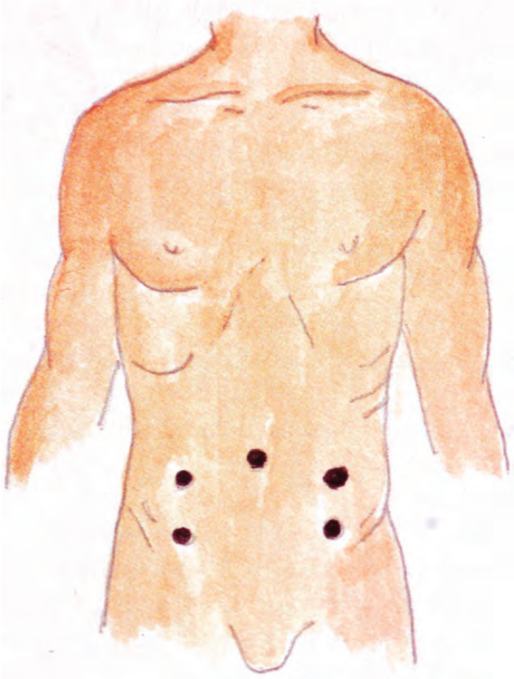

Figure 74.7 Fan configuration commonly used for performing pelvic lymph node dissection.

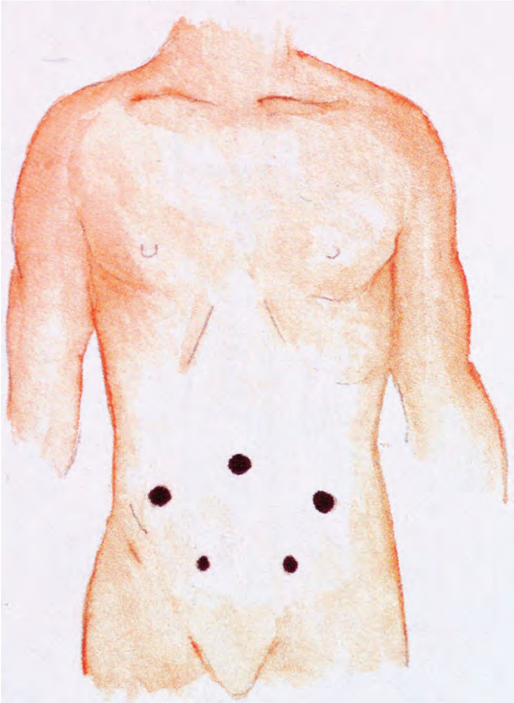

Figure 74.8 Modified fan configuration commonly used for laparoscopic radical prostatectomy and retropubic bladder neck suspension.

a vesicourethral anastomosis may need to be performed, or it may be useful in laparoscopic bladder neck suspension.

For pelvic procedures, the patient is often positioned in a dorsal lithotomy position. In this position the diamond trocar array (Figure 74.9) gives the surgeon maximal freedom in moving the suprapubic trocar, but they need to be aware that the medial umbilical ligament can interfere with instruments passed through the lower midline trocar of the diamond configuration. The diamond configuration is also used when a pelvic lymphadenectomy is being performed in conjunction with a laparoscopic-assisted perineal prostatectomy.

Laparoscopic bladder neck suspension

When using a diamond trocar array (Figure 74.9) in performing a Burch bladder neck suspension, secondary trocar size depends on the reconstructive instrumentation utilized [17, 18]. For example, if an Endo Stitch® suturing device is used, all trocars placed will be 10/12 mm. If conventional suturing is used for securing the anterior vaginal wall to Cooper's ligament, then 5-mm trocars can be substituted. Alternatively, Frede *et al*. recommended a modified fan configuration (Figure 74.8) for laparoscopic bladder neck suspension [2].

Laparoscopic varix ligation/orchiopexy

When performing a varix ligation (unilateral or bilateral), three trocars are usually needed [19] (Figure 74.10). They are arranged in a triangular configuration. In addition to the primary umbilical 10/12-mm trocar or a 5-mm trocar for the camera, two secondary trocars are placed in the mid-clavicular line at the level of the anterior superior iliac spine. One of these mid-clavicular trocars is used for clipping the spermatic veins. This trocar arrangement also can be used when clipping the spermatic vessels in a staged orchiopexy.

Several 5-mm secondary trocars are needed to perform a laparoscopic primary orchiopexy for the treatment of intra-abdominal testes [20] (Figure 74.10). A 5-mm umbilical primary trocar is needed for the camera. Two 5-mm trocars are placed in the mid-clavicular line at the level of the anterior superior spine for dissection of the spermatic vessels. A final 5-mm trocar is placed through the scrotum into the peritoneal cavity for transfer of the intra-abdominal testes into the scrotum. This is accomplished by backfeeding a 5-mm trocar over a 5-mm straight grasper that has been passed through the mid-clavicular trocar (ispilateral to the intra-abdominal testes) over the pubic ramus and through the scrotal incision. This grasper is utilized to gently bring the intra-abdominal testicle into the scrotum.

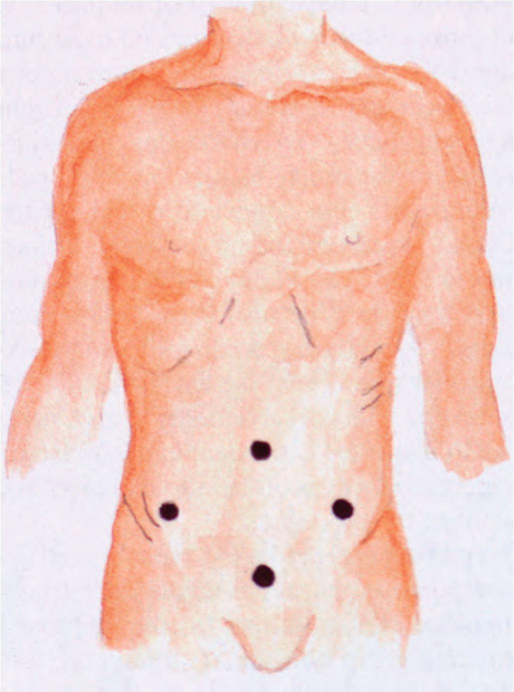

Figure 74.9 Diamond trocar configuration is utilized for either pelvic lymphadenectomy or bladder neck suspension.

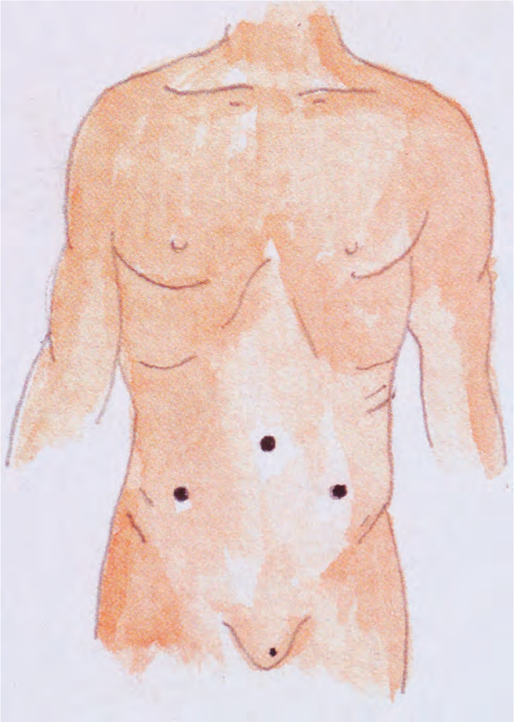

Figure 74.10 Triangular trocar configuration used for varix ligation (unilateral or bilateral) and primary orchiopexy. A 5-mm scrotal trocar is used to deliver the testicle into the scrotum.

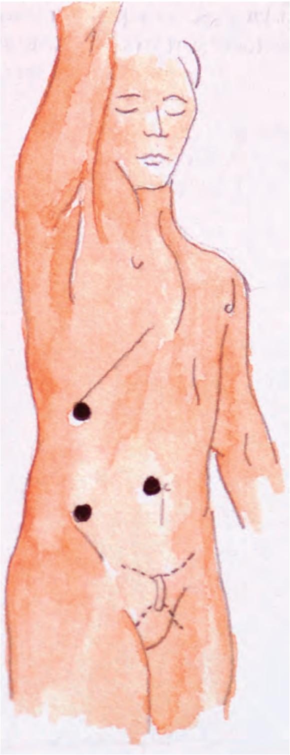

Figure 74.11 Three trocars are utilized to perform a reconstructive upper ureteral procedure. An optional 5-mm trocar can later be placed in the anterior axillary line for refraction of a large redundant renal pelvis and as the exit point for a retroperitoneal drain.

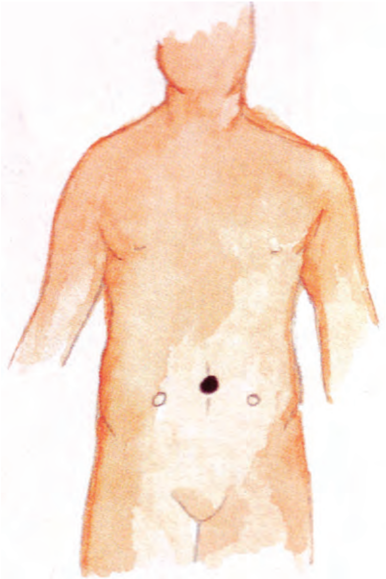

Figure 74.12 Trocar arrangement for access to the pelvic ureter. A triangular arrangement is advocated with a 10/12-mm port at the umbilicus and two 5-mm ports as shown.

Pure laparoscopic ureter procedures

Port placement to access the abdominal ureter includes a port placed just lateral to the umbilicus. Another port is placed below the costal margin in the mid-clavicular line and the third trocar is positioned in the lower ipsilateral quadrant in the mid-clavicular line (Figure 74.11). Trocar placement for the lower pelvic ureter includes a trocar at the umbilicus. One to two ports are placed in each lower quadrant 2 cm medial to the corresponding anterior iliac spine. This configuration provides optimal access to the pelvic ureter from the iliac vessels to the ureterovesical junction (Figure 74.12). When access to the entire ureter is a concern, a combination port placement is necessary (Figure 74.13). Three to four trocars are required to perform a transperitoneal laparoscopic procedure on the upper ureter [21]. A periumbilical 12-mm primary trocar is used for the videoendoscope. A 10/12-mm trocar is placed in the mid-clavicular line at the level of the umbilicus. Two 5-mm trocars are used, one in the epigastric area and one in the anterior axillary line between the iliac crest and 12th rib. Suture passage is via the mid-clavicular trocar, while suturing is performed via both the mid-clavicular and epigastric trocars (port placement for pyeloplasty or ureterolysis

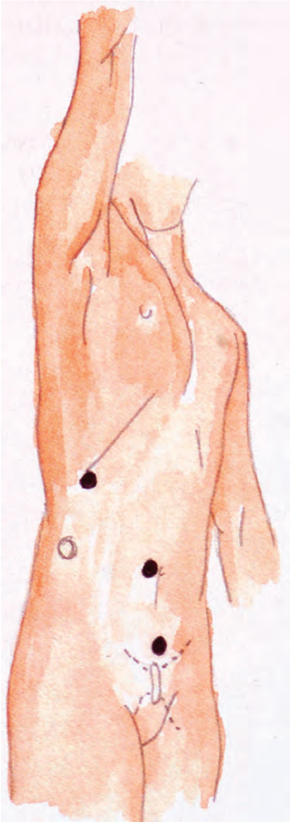

Figure 74.13 Combination port placement for access to the entire ureter (modified from Figure 60.6 in *Smith's Textbook of Endourology*, 1st edn).

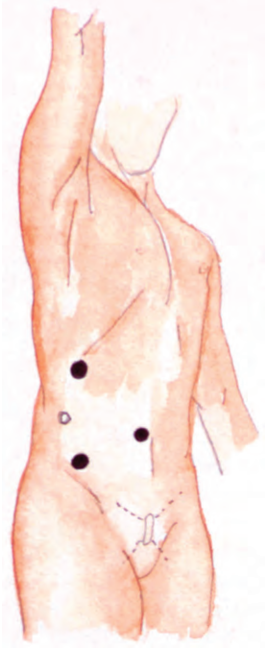

Figure 74.14 Port placement for laparoscopic pyeloplasty is similar to the abdominal ureter port placement. However, an additional 5-mm trocar may be placed in the anterior axillary line midway between the costal margin and iliac crest for retraction. Port placement for laparoscopic ureterolysis is similar to that for laparoscopic pyeloplasty. In this case the 5-mm port is used for retraction.

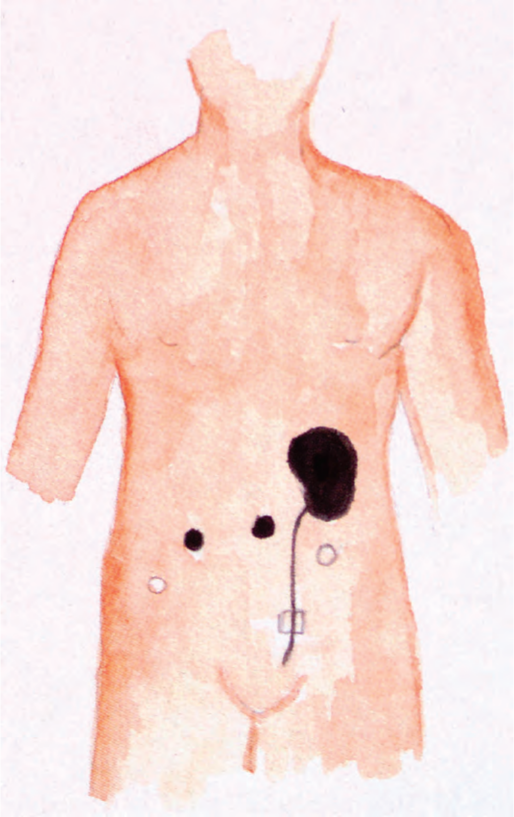

Figure 74.15 Trocar configuration for a left lower laparoscopic ureterolithotomy. The 10/12-mm port is placed contralateral to the side in question.

is shown in Figure 74.14). Ureterolithotomy port placement is dependent on whether the upper or lower ureter is involved. A stone located in the upper ureter can be approached similar to a pyeloplasty procedure, while for lower ureteral stones the 10-mm port is placed contralateral to the side to be addressed (Figure 74.15).

Pure laparoscopic renal procedures

Nephrectomy

Three to five trocars are needed to carry out a transperitoneal laparoscopic nephrectomy and other laparoscopic renal surgeries [22] (Figure 74.16). A 10/12-mm periumbilical cannula is used for the camera. The dissection ports are placed at the epigastric and mid-clavicular position, similar to the positioning used for performing a laparoscopic procedure on the upper ureter. If an endovascular stapler or vascular "bulldog clamp" is to be utilized for vascular control, one or both of these trocars needs to be a 10/12-mm trocar(s). Additional laterally placed trocars are used for retraction of the renal helium, lateral dissection, or suture repair, as well as treatment probe insertion for nephron-sparing procedures. In all cases the lateral trocars are either 5 or 8 mm in size, with the exception of cytoreductive nephrectomy when a endovascular stapler is needed to control the parasitic vessels; in this case 10/12-mm lateral trocars are used.

Nephroureterectomy

Trocar configuration for laparoscopic nephroureterectomy is identical to the configuration utilized for the laparoscopic nephrectomy. An additional suprapubic port is used to secure the bladder cuff (Figure 74.17). Some surgeons utilize a vascular GIA stapler to complete this task. When using the GIA stapler, a 10/12-mm suprapubic trocar is needed. Other surgeons perform primary resection with subsequent conventional suturing reconstruction of the bladder. This requires a 5-mm trocar.

Donor nephrectomy

Laparoscopic transperitoneal donor nephrectomy requires the same primary three trocars utilized for laparoscopic simple nephrectomy and additional retraction trocars. For left laparoscopic donor nephrectomy, a 15-mm suprapubic trocar is used for medial retraction

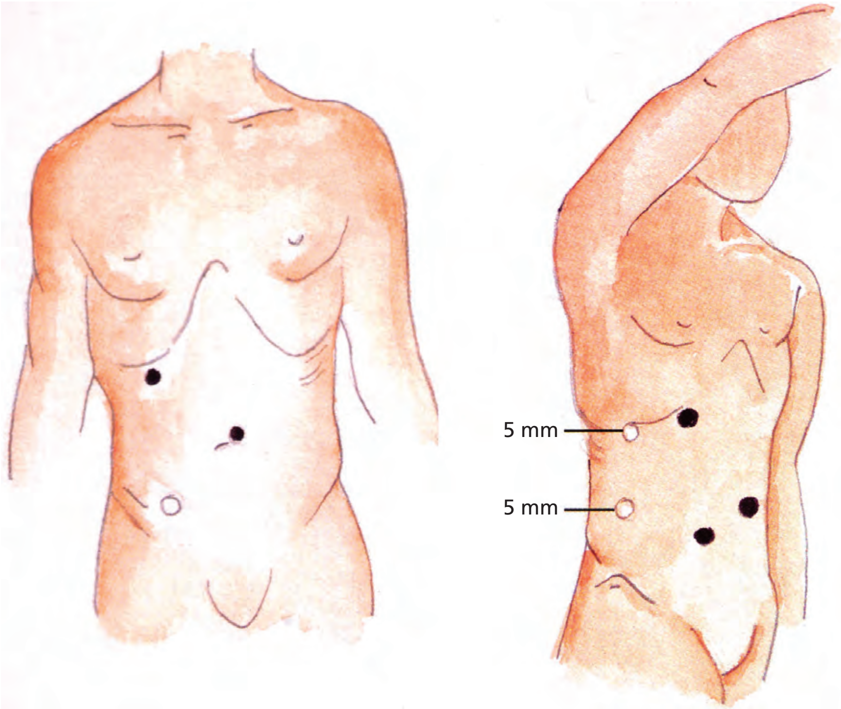

Figure 74.16 Trocar configuration for laparoscopic nephrectomy/partial nephrectomy varies from three (left) to five trocars (right). Two 12-mm ports are placed initially at the umbilicus and upper mid-clavicular line. Three other ports, which may be 5-mm ports, are placed at the lower mid-clavicular line, lower anterior axillary line, and upper anterior axillary line. At times the upper axillary line port may be changed for a 12-mm port.

of the bowel (Figure 74.18). For right-sided procedures this trocar is moved upward to the epigastic region. Trocar configuration for left-sided hand-assisted donor nephrectomy starts with an epigastric placed hand-assisted device. In addition, two 12-mm ports are placed at the umbilicus and mid-clavicular area with an optional (if retraction is needed) lateral 5-mm port placed at the anterior axillary line (Figure 74.19).

Partial nephrectomy/calyceal diverticulectomy

During laparoscopic partial nephrectomy or calyceal diverticulum resection, laterally placed trocars are used for renal resection, renal reconstruction, or drain placement (Figure 74.16). It is important to remember in the morbidly obese patient to move all trocars laterally and to place the midline trocars in the paramedian line [23].

Hand-assisted nephrectomy

The trocar configuration for hand-assisted laparoscopic nephrectomy (HALN) is very different from both transperitoneal and retroperitoneal laparoscopic nephrectomy. Secondary trocar arrangement is dependent on placement of the hand-assisted device and is arranged to optimize visualization with the camera port and dissection with the two working instruments. As with traditional laparoscopic procedures, these three ports are arranged in triangular configurations. For left-sided HALN, the hand-assisted device is placed within the periumbical area with the working port and camera ports placed in the mid-clavicular line and anterior axillary line, respectively (Figure 74.19A). For right-sided HALN, the hand-assisted device is placed in the right lower quadrant with the working and camera ports placed in the periumbilical area and epigastric area, respectively (Figure 74.19B).

Adrenalectomy

Laparoscopic adrenalectomy has multiple trocar placement configurations, depending on approach (transperitoneal vs retroperitoneal vs thoracic) and side of interest (right or left). For right-sided transperitoneal adrenalectomy, the trocars are arranged in a circular configuration. The camera port (10/12 mm) is placed in the periumbilical region. The dissection trocars are positioned in the anterior axillary and mid-axillary line. A fourth port is placed between the two above trocars and utilized for retraction of the liver (Figure 74.20). An optional fifth port can be placed in the posterior axillary to retract the upper pole of the kidney. Trocars are placed

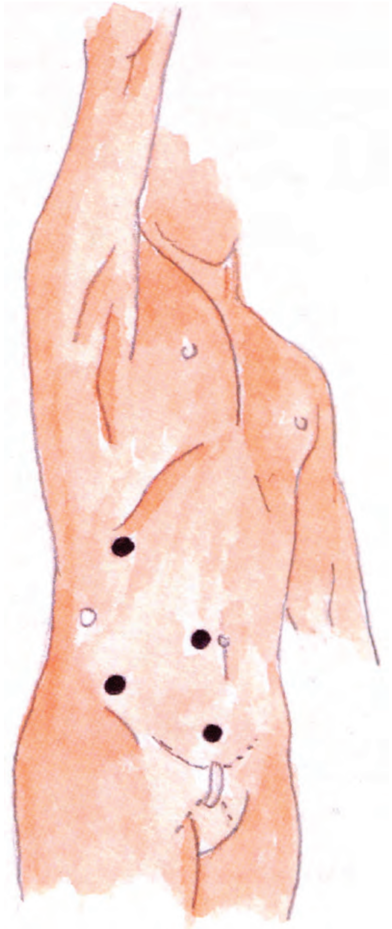

Figure 74.17 Trocar arrangement for laparoscopic nephroureterectomy. The 12-mm port is used for passing the GIA stapler across the bladder cuff. Again, placing a 5-mm port for retraction is optional.

in similar fashion for performing a left transperitoneal adrenectomy. Lastly, Gill *et al.* have reported thorascopic transdiaphragmatic adrenalectomy with the four-port configuration depicted in Figure 74.21.

Retroperitoneal lymph node dissection

Four to five ports are usually used. Some surgeons recommend only 10/12-mm ports to allow maximal flexibility and this enables use of larger grasping forceps for specimen retrieval. Port positioning for laparoscopic retroperitoneal lymph node dissection for testicular cancer is a diamond-shaped configuration with the camera port at the umbilicus. Two 12-mm working ports are placed in the mid-clavicular line, one at the costal margin and one at the level of the anterior superior spine. A lateral retraction port is placed in the anterior axillary line at the level of the umbilicus (Figure 74.22).

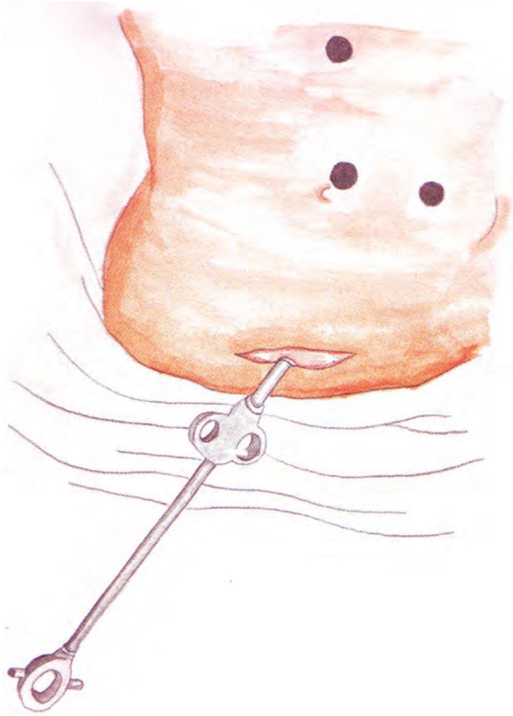

Figure 74.18 Trocar arrangement for a left laparoscopic donor nephrectomy. A suprapubic "thoracoport" and Endo Catch II entrapment device may be useful at the extraction site.

Robot-assisted laparoscopic procedures

The da Vinci robotic system has become widely used in the USA and Europe for urologic procedures which require reconstruction (prostatectomy, partial nephrectomy and pyeloplasty). This section will demonstrate the recommended trocar configuration for commonly used robot-assisted laparoscopic procedures (prostatectomy, nephrectomy, partial nephrectomy, and pyeloplasty).

Prostatectomy

Port placement for robot-assisted laparoscopic radical prostatectomy is based on the most consistent anatomic landmark, the pubic bone in the midline. Another consideration in any robot-assisted procedure is that the maximum working length of the da Vinci instruments is 25 cm. Therefore, for robot-assisted prostatectomy all robotic instrument ports are positioned approximately 15 cm (not to exceed 18 cm) from the patient's midline of the public bone. The 12-mm scope port is positioned superior umbilically within 2 cm of the umbilicus. All robotic working ports are 8 mm in diameter and are three- or four-arm, based on the da Vinci robotic model. The right robotic working port (labeled 1 and colored yellow) is positioned 10–12 cm (one hand's width) from the midline on a line to the right anterior iliac spine

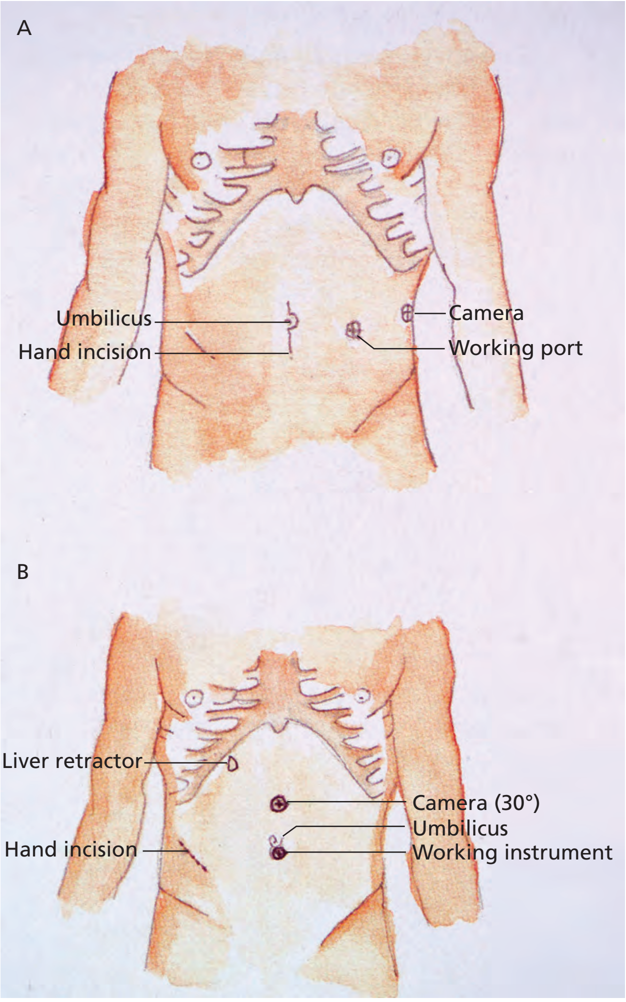

Figure 74.19 (A) Positioning of hand-assisted device and trocar configuration for (A) left-sided and (B) right-sided hand-assisted nephrectomy.

slightly below the level of the scope port. The left robotic working port (labeled 2 and colored green) is positioned 10–12 cm from the midline on a line to the left anterior superior iliac spine, slightly below the scope port. The third working arm port (labeled 3 and colored red) is positioned on the patient's right side 2–3 cm from the right superior iliac crest and within 8 cm (one hand's width) from the right robotic working port [1]. Assistant port 1 (white, 12 mm) is positioned on the patient's left side, one hand's width lateral to the left robotic working port (labeled 2 and colored green). Assistant port 2 (black, 5 mm) is positioned on the patient's left side 6–8 cm above the left robotic working port (Figure 74.23).

Nephrectomy

Robot-assisted nephrectomy and partial nephrectomy has two types of trocar configurations: medial camera

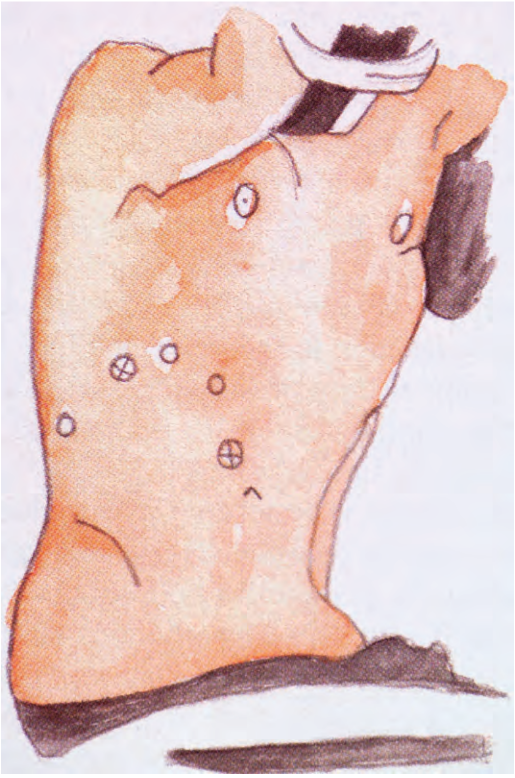

Figure 74.20 Four ports are typically used for a transperitoneal laparoscopic adrenalectomy. The first trocar is usually placed in the anterior axillary line. Next, two others are placed under vision at the subcostal mid-clavicular and midline. After the kidney has been identified, a fourth trocar may be placed subcostally in the posterior axillary line.

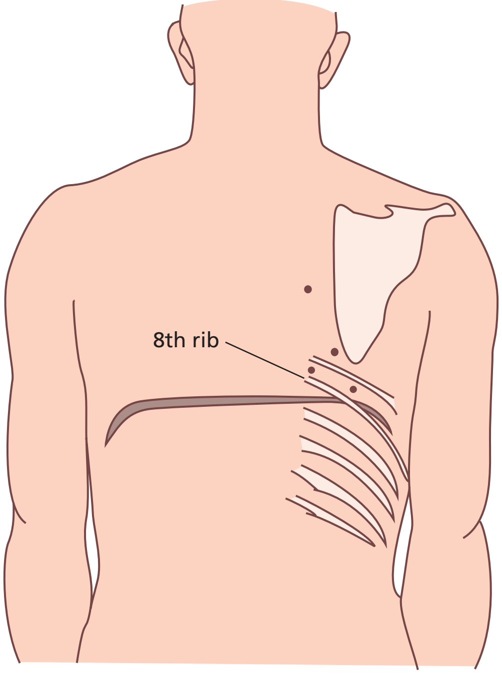

Figure 74.21 Trocar configuration using Gill's right transthoracoscopic approach to an adrenalectomy [24].

port placement and lateral camera port placement. General principles to keep in mind when placing trocars is to triangulate the ports toward the renal hilum, and to create obtuse angle of approximately 100° between the robotic ports and camera port as the vertex. The medial camera port placement technique uses a 0° or 30° angle-down scope with the patient in a full or modified flank patient position. The major advantage is a viewing perspective similar to that with traditional laparoscopic renal surgery. The lateral camera port placement technique uses a 30° angle-up laparoscope with the patient positioned in the full flank position. Major advantages of the lateral camera port are the aerial viewing perspective, reduced number of robotic arm and camera arm collisions, and the optimized working space for the patient-side assistant.

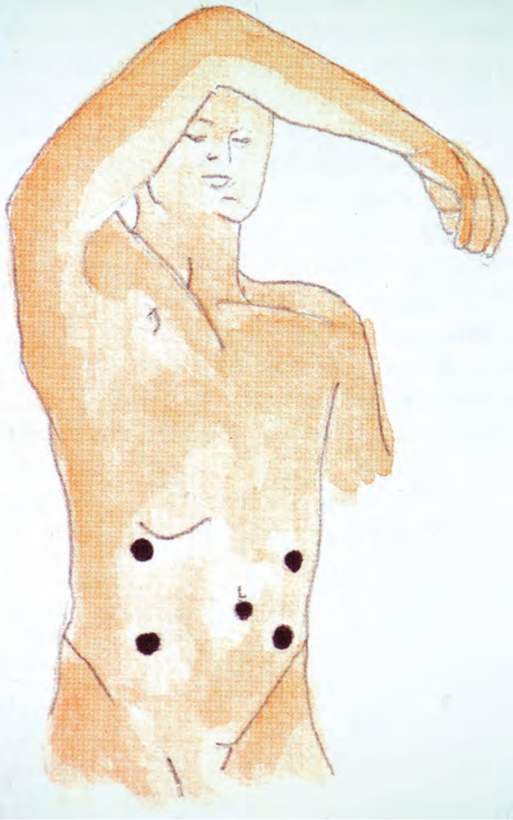

Figure 74.22 Trocar positioning is in an "X" arrangement for a right retroperitoneal lymphadenectomy for testicular cancer. Usually the surgeon will use laparoscopic scissors at the infraumbilical port and grasping forceps at the lower quadrant port. The contralateral port is optional and may be used by an assistant. The upper right quadrant port is the camera site.

For medial camera port configuration for nephrectomy and partial nephrectomy procedures, the camera port (12 mm) is placed in the periumbilical area (Figure 74.24A). For left-sided procedures, the robotic instrument ports are placed a hand's width away from the camera port with each trocar (8 mm) at least 3 cm from the iliac crest (yellow) and costal margin (green). For right-sided procedures, the robotic working ports are placed a hand's width away from the camera, with each trocar (8 mm) at least 3 cm from the costal margin (yellow) and iliac crest (green). Also, the robotic working ports are placed a hand's width away from the camera, with each trocar (8 mm) at least 3 cm from the costal margin (yellow) and iliac crest (green) (Figure 74.24B).

For the lateral camera port configuration, the camera port (12 mm) is placed a hand's width from the costal margin, between the mid-clavicular and anterior axillary line. For right-sided procedures, both robotic instrument ports (8 mm) are placed a hand's width medial from the camera port (Figure 74.25A), with the right robotic working port placed at least 3 cm from the costal margin and the left robotic working port at least 3 cm from iliac crest. For left-sided procedures the robotic instrument working ports are both placed a hand's width medial to the camera port (Figure 74.25B), with the right robotic working port placed at least 3 cm from the iliac crest and the left robotic working port at least

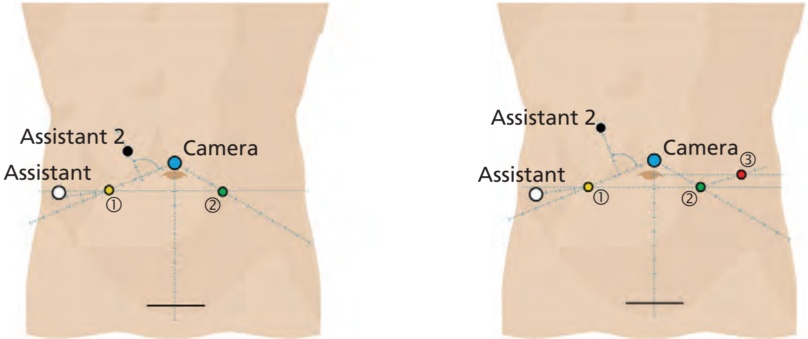

Figure 74.23 Trocar configurations for robot-assisted laparoscopic radical prostatectomy for three-arm (left) and four-arm robots (right). Camera port, blue; right robotic working port, yellow; 1, left robotic working port, green; 2, assistant port, white; assistant 2, black; third robotic port, red 3 (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

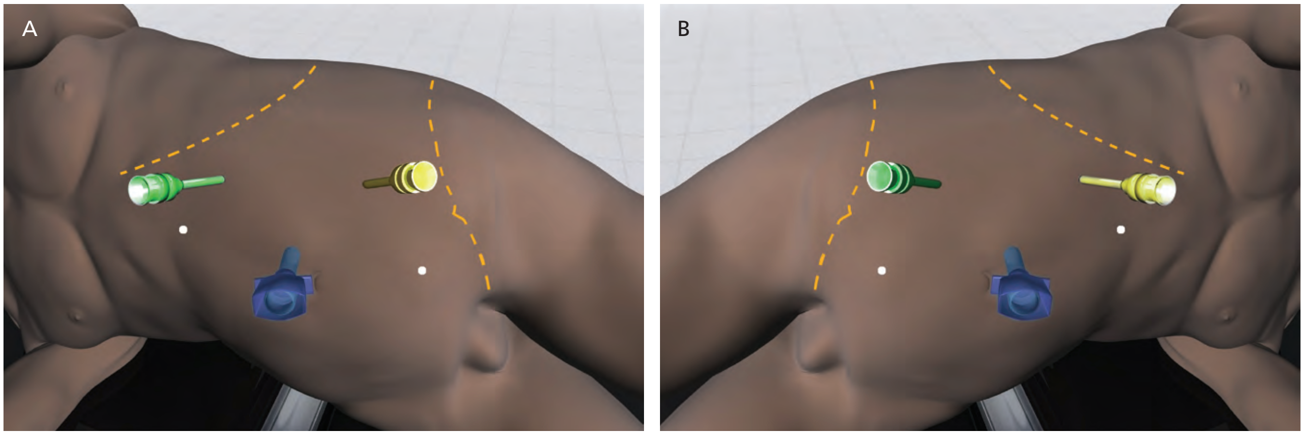

Figure 74.24 Robot-assisted nephrectomy/partial nephrectomy for (A) left-sided and (B) right-sided "medial" camera port configuration: Camera port, blue; left robotic working port, green; right robotic working port, yellow; assistant ports, white (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

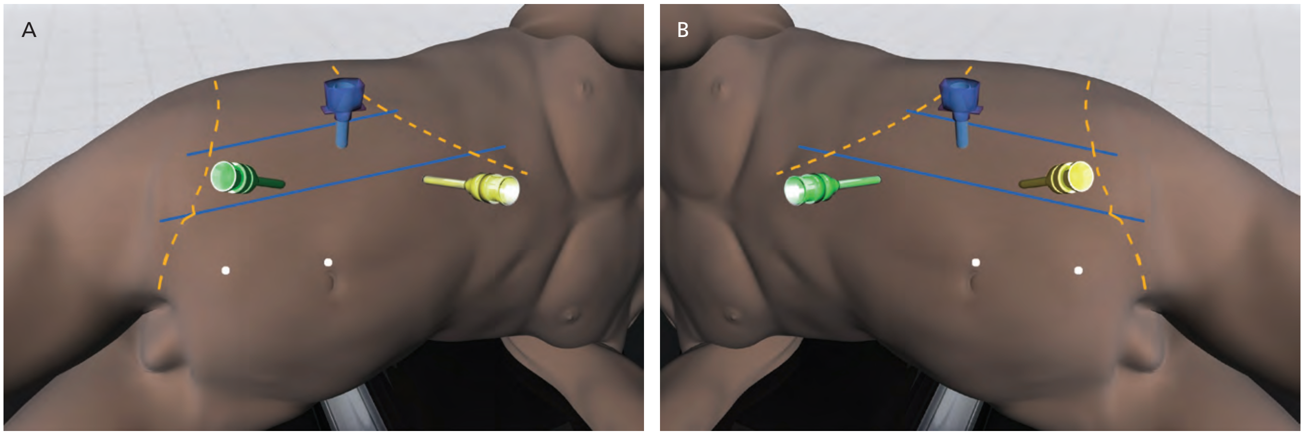

Figure 74.25 Robot-assisted nephrectomy/partial nephrectomy for (A) right-sided and (B) left-sided "lateral" camera port configuration. Camera port, blue; left robotic working port, green; right robotic working port, yellow; assistant ports, white (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

3 cm from the costal margin. The superior assistant port (12 mm)- is placed periumbilical and the inferior assistant port (5 mm) 8 cm inferior to the umbilicus and at least 4 cm from the inferior robotic instrument port.

Pyeloplasty

For robot-assisted laparoscopic pyeloplasty, the camera port is placed at the umbilicus. For obese patients this port can be moved lateral to the rectus muscle. The robotic working ports are placed 8–10 cm lateral to the camera port. For right-sided procedures, the right robotic instrument port is 3 cm from the costal margin and the left robotic instrument port is 3 cm from the iliac crest (Figure. 74.26A). For left-sided procedures, the right robotic instrument port is 3 cm from the iliac crest and the left robotic instrument port is 3 cm from the costal margin (Figure 74.26B).

Conclusions

With careful planning, secondary trocars can be placed safely and effectively under videoendoscopic vision. For surgeons who are at an early stage on the learning curve, we recommend using an established trocar placement for a given procedure and suggest modifying this as experience is gained to fit personal preferences and experience with established trocar arrangements. As the experienced laparoscopic surgeon well knows, the prudent arrangement of the laparoscopic trocars can mean the difference between effortlessly orchestrated procedures and a tiresome mêlée.

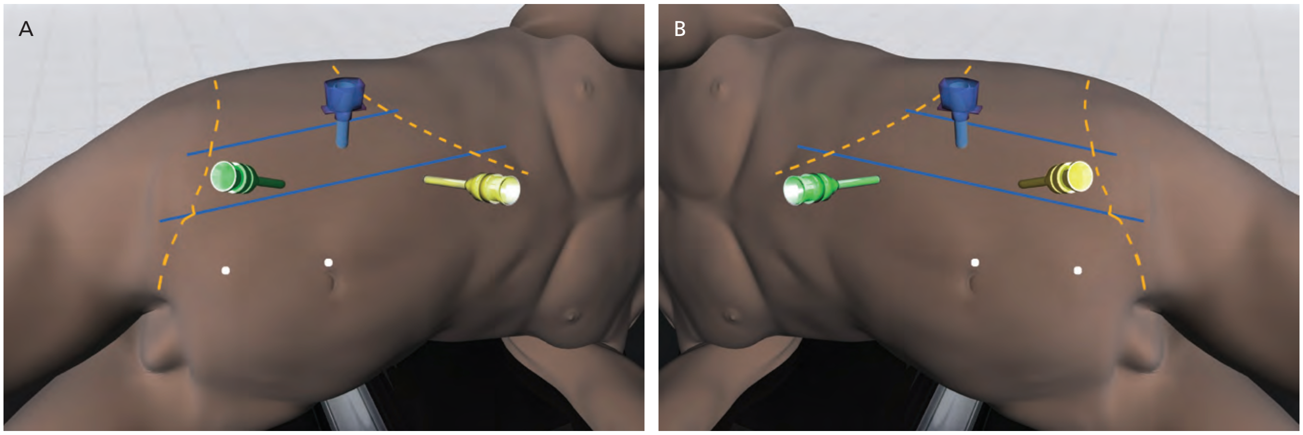

Figure 74.26 (A) Robot-assisted pyeloplasty for (A) right-sided and (B) left-sided port configuration. Camera port, blue; left robotic working port, green; right robotic working port, yellow; assistant ports, white (© 2010 Intuitive Surgical Inc, Sunnyvale, CA, USA).

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CHAPTER 75

Retroperitoneal Access

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Introduction

The first technical part of any urologic laparoscopic or robotic procedure involves obtaining access to either the peritoneum (see Chapter 74) or the retroperitoneal space. Access and trocar placement is of critical importance as improper placement may lead to difficulty later. In this chapter we outline the necessary steps for proper patient position, access, and secondary trocar placement for both renal retroperitoneal surgery and pelvic extraperitoneal surgery. In addition, we outline potential exclusion criteria for retroperitoneal renal/adrenal surgery and extraperitoneal pelvic surgery. Finally, we briefly summarize critical issues related to laparoscopic exit at the end of the case.

Retroperitoneal renal/adrenal surgical access

Direct access to the retroperitoneum for renal or adrenal surgery may offer several potential advantages over the transperitoneal approach. Ligation of the renal artery and vein during radical nephrectomy may be aided by circumventing the need for bowel dissection. In addition, in cases of posterior small renal masses, direct access to the posterior aspect of the kidney may obviate the need for full renal mobilization. Patients with multiple prior transabdominal surgeries or large anteriorly located mesh may also benefit from the retroperitoneal approach for renal or adrenal surgery.

Patient exclusion

A surgeon's experience often dictates their preference between transperitoneal and retroperitoneal access. No definitive exclusion criteria exist for retroperitoneal access, although a few cases may present more challenges for retroperitoneal surgery. As such, the novice surgeon should be selective when choosing patients. Renal tumors greater than 10 cm in size are best approached via a transperitoneal approach. Those located on the posterior hilar aspect may present challenges with retraction and lifting of the kidney and as such may be better suited for the transperitoneal approach. A patient with prior open retroperitoneal surgery (e.g. a partial nephrectomy) is best approached transperitoneally or in an open fashion. Prior percutaneous access for stone surgery has not presented a significant challenge in our experience.

Patient position and access technique

After induction of general anesthesia, the patient is positioned in the full flank position. The patient is secured to the table with 3-inch tape at the level of the chest (without impeding mechanical ventilation) and hips. Securing the patient in this way allows the table to be rotated from right to left. We do not find it necessary to use a bean bag. The table is flexed and an axillary roll is placed. Pillows are placed between the legs and pressure points (knees, hips) are properly padded. The

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upper extremity is placed in a double arm board. The tip of the 12th rib is marked with semi-permanent ink prior to sterile prep and drape, as palpation of the rib after preparation and gloving may be impaired, especially in the obese patient. After sterile preparation and draping, a line is extended from the anterior superior iliac spine in a cephalad direction, and the right surgical port is inserted along this line (Figure 75.1). Another line is drawn at the level of the extensor muscles of the back. At the intersection of this line and the lower aspect of the 12th rib, the left trocar is inserted.

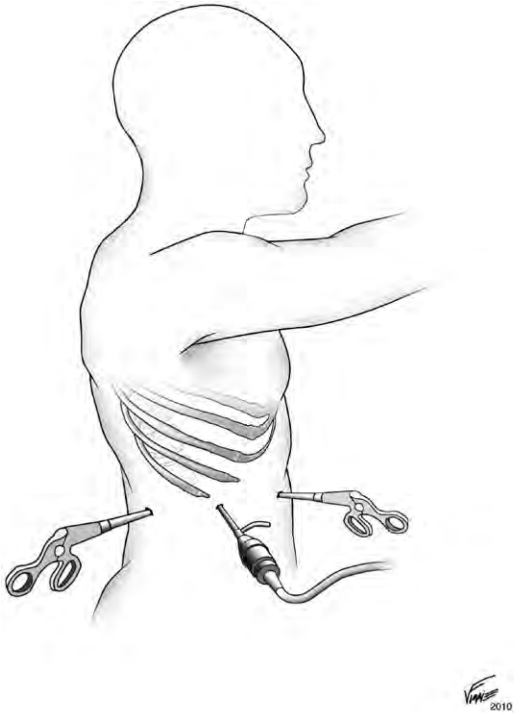

Figure 75.1 Trocar placement for retroperitoneal renal/adrenal surgery. Patient is positioned in the full flank position. All three trocars line up in a straight line.

At the tip of the 12th rib, a 1.5-cm incision is made. The incision is carried down to the level of the external oblique fascia. A 1-cm incision is made in the fascia with Bovie cautery. S-retractors are used to split the external oblique muscle and often the internal oblique muscles down to the lumbodorsal fascia. The lumbodorsal fascia is incised with cautery of about 1 cm in length. The surgeon's index finger is inserted into the retroperitoneal space with the tip of the finger aimed in the posterior direction, but staying anterior to the psoas muscle which is readily palpable (Figure 75.2A). The lower pole kidney can typically be felt. Enough space is created posterior to the kidney so as to accommodate placement of the round dissecting balloon (Covidien, Mansfield, MA, USA), which is placed posterior to the kidney. The balloon is pumped 20 times (~400 mL). At this point a 30° lens, 10-mm laparoscope is inserted through the dissecting balloon port and the anatomy is appreciated. The psoas muscle can typically be assessed posteriorly and the peritoneum anteriorly. An additional 400 mL is insufflated into the balloon (800 mL in total) (Figure 75.2B). The balloon dissecting trocar is deflated and a balloon working trocar (Covidien) is placed. Retropneumoperitoneum is achieved at a pressure of 15 mmHg.

Placement of secondary trocars

Under direct vision the two remaining trocars are placed. The surgical left hand is placed under the 12th rib in line

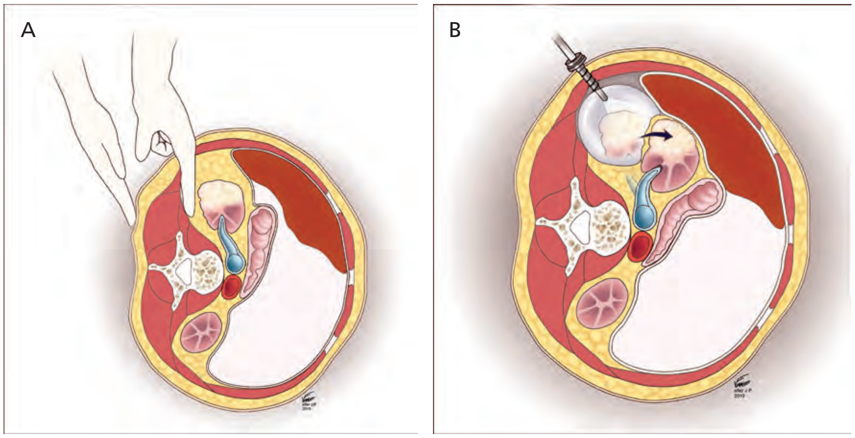

Figure 75.2 (A) Surgeon's index finger inserted through the lumbodorsal fascia into the retroperitoneal space anterior to the psoas muscle. (B) Balloon dissection of the retroperitoneum. The round-shaped balloon is posterior to the kidney during dissection.

with the extensor muscles of the back. This trocar may be angled in a slightly more cephalad direction, which will decrease the amount of torque on the trocar and surgeon fatigue during the case. The surgical right trocar is placed in line with the previously marked anterosuperior iliac spine (ASIS) line. The peritoneum may be visualized and, if necessary, may be dissected more medially using the surgical left trocar and a laparoscopic Kitner instrument. We use two 12-mm trocars for the left and right operating trocars. The surgical left trocar, camera trocar, and right trocar are all placed in a straight line (Figure 75.1).

Access for extraperitoneal pelvic surgery

The application of pelvic extraperitoneal surgery is best for robot-assisted laparoscopic prostatectomy. Other urologic applications include distal ureter surgery, partial cystectomy of anterior lesion, and limited pelvic lymph node dissection. An advantage of the technique is decreased need for a steep Trendelenburg position during the procedure. Patients with multiple prior abdominal surgeries (but virginal extraperitoneal space) with known or suspected bowel adhesions may be ideal candidates. In the event of vesicourinary anastomotic leak, the leak is contained in the extraperitoneal space. Disadvantages include the smaller working space and the higher rate of pelvic lymphocele if bilateral lymph node dissection is performed.

Patient exclusion

The transperitoneal approach is best for patients with prior extraperitoneal surgery, such as open simple prostatectomy, open bladder stone removal, and renal transplantation. In such cases, it may not be possible to dissect the space of Retzius with the balloon for safe placement of lateral trocars.

Patient position and access technique

The patient is placed in the supine position. Lower extremities may be placed in Yellofin® leg holders or using a split-leg table. An orogastric tube is placed by anesthesiology, and the patient is prepared and draped sterilely. The pubic bone is identified and an infraumbilical incision of about 1.5 cm in length is made in the midline. S-retractors are used for retraction and dissection is continued to the external fascia. Stay sutures of 0-vicryl are placed in the external fascia, caudal and cephalad to the incision site on the fascia. Holding the lower fascia anteriorly, the external fascia is incised. The rectus muscle belly is separated in the midline. A very thin layer of investing fascia of the muscle (no proper posterior sheath exists at this level) is identified and incised with scissors or blunt index finger dissection. The surgeon's index finger is inserted into the extraperitoneal space. A kidney-shaped dissecting balloon (Covidien) is inserted into the space in the direction of the pubic bone (Figure 75.3). The balloon is insufflated 30 times (~600 mL). Under direct vision with a 10-mm laparoscope, insufflation is continued until the pubic bone is visualized from within the balloon. The dissecting balloon is desufflated and removed. Care is taken to avoid distraction of the inferior epigastric vessels during insufflation. A Hasson trocar of the surgeon's choice is then placed to serve as a camera trocar (12 mm for robotic cases; 10 mm for laparoscopic cases).

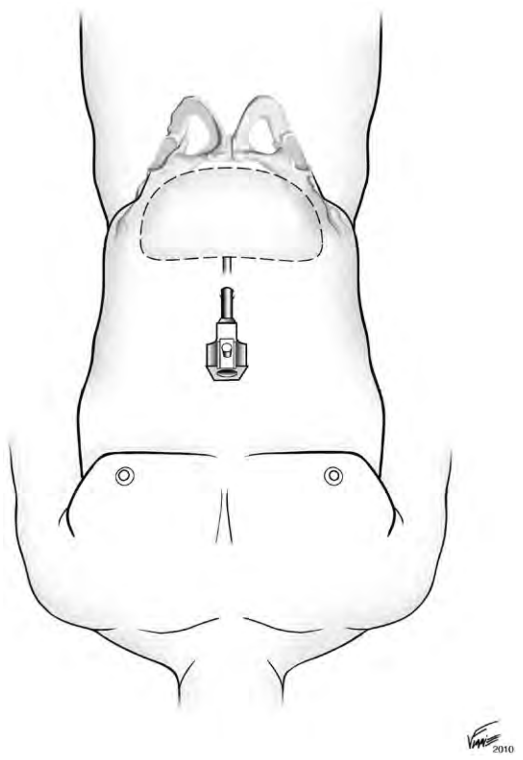

Figure 75.3 Extraperitoneal balloon dissection for laparoscopic or robotic pelvic surgery.

Placement of secondary trocars

It is necessary to push the peritoneum in a cephalad and lateral direction to allow placement of lateral secondary trocars. Despite the use of the kidney-shaped dissecting balloon, we find it necessary to use a 10-mm laparoscope and some gentle abdominal pressure to sweep the peritoneum in a cephalad and lateral direction. Pulsations of the iliac vessels should be noted to avoid inadvertent injury.

Laparoscopic exit

Although great emphasis is placed on initial access, of equal importance is the exit or removal of trocars at the end of the case. It may be challenging for the surgeon to follow through with these steps due to fatigue, but it is necessary for them to maintain vigilance at the end of the case. Details of the laparoscopic exit are given in Chapter 29. Here we describe the important features of exit from retroperitoneal and extraperitoneal surgery. If an inadvertent entry was made into the peritoneum during retroperitoneal surgery, the surgeon should explore this area and insure no bowel injury has occurred. The surgeon may decrease insufflation pressures to 10 mmHg or less to insure no bleeding is visualized. It is standard practice to remove all trocars under direct vision. In the event of bleeding from trocar sites, a Carter–Thomas closing device may be used to close the fascia and obtain hemostasis. Large 12-mm trocar sites may be closed with the Carter–Thomas closing device and Vicryl suture. For extraperitoneal pelvic surgery it is prudent to create a small peritoneal window at the level of the umbilicus at the end of the case to expel pneumoperitoneum that will have accumulated.

CHAPTER 76

Basic Hand-Assisted Laparoscopic Techniques

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Introduction

The introduction of hand-assisted laparoscopic surgery (HALS) has contributed greatly to the widespread adoption of laparoscopy for renal surgery. With each passing year, more urologists are performing laparoscopy, specifically laparoscopic nephrectomy. The increase in use, however, was very modest in the first decade following Clayman *et al.*'s initial report [1]. Why did laparoscopic nephrectomy take so long to catch on, but then subsequently become a standard procedure? This history of laparoscopic nephrectomy contrasts starkly with that of other laparoscopic procedures introduced in the same time period (late 1980s to mid 1990s). Laparoscopic cholecystectomy, laparoscopic pelvic lymph node dissection [until its utility was reduced by prostate-specific antigen (PSA) risk profiling], laparoscopic gastric fundoplication, and laparoscopic hysterectomy all achieved widespread use soon after their introduction. Why was laparoscopic nephrectomy different? The primary reason proposed in the mid 1990s was that laparoscopic nephrectomy was too difficult for the average urologist to develop and to maintain the necessary operative skills, given the relative infrequency of nephrectomy in a typical urology practice. There were other factors as well, including concern about oncologic efficacy, the inefficiency of increased operative time, and safety of the procedure in case of vascular injury.

Although there likely were many developments that spurred on the widespread acceptance of laparoscopic nephrectomy, HALS was a major factor. HALS addresses many of the perceived problems with laparoscopic nephrectomy: it technically simplifies the procedure, which allows even urologists with a low-volume practice to develop and maintain skills; it facilitates wide dissection and intact specimen removal, which may provide some reassurance as to the oncologic efficacy of the procedure (although there is no evidence that HALS provides any different outcome from standard laparoscopic nephrectomy in this regard); it reduces operative time for most surgeons; and it provides more rapid control of vascular injury and may reduce the need for conversion to open surgery. Once a critical mass of surgeons started performing laparoscopic nephrectomy, combined with patient demand, its popularity was inevitable.

Following a brief history of hand assistance, this chapter first describes the HALS devices that are currently available along with some general principles of their application. Then, the results of HALS are provided with emphasis on series that compare HALS to other laparoscopic techniques. Finally, an assessment of the role of HALS in urology is made.

History

As with many innovations in surgery, the initial forays into HALS were met with skepticism [2]. In 1993, Boland *et al*. reported their experience (starting in 1992) with insertion of a gloved hand through a tight fascial incision to allow direct manual organ dissection and removal while maintaining pneumoperitoneum during laparos-

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copy [3]. Tierney *et al.* [4] and Tschada *et al*. [5] reported laparoscopic radical nephrectomy using this technique in 1994 and 1995, respectively. Commercial devices to facilitate laparoscopic hand assistance were under development by this time [6], and in 1996 Bannenberg *et al.* reported hand-assisted laparoscopic nephrectomy in a porcine model using a prototype of the first commercial HALS device [7]. Later that same year, Nakada *et al*. performed the first clinical laparoscopic nephrectomy with a commercial HALS device [8]. In 1997, Keeley *et al.* reported the first HALS nephroureterectomy [9], and in 1998 Wolf *et al.* described the first HALS donor nephrectomy [10]. HALS was soon applied to a number of other urologic laparoscopic procedures. The introduction of improved commercial HALS devices that did not require the use of a sleeve further accelerated the acceptance of HALS in urology.

Devices for hand-assisted laparoscopy

The first commercial HALS devices had sleeves that wrapped around the arm and were affixed to the abdomen with adhesive: the Pneumo Sleeve (Dexterity Surgical, Roswell, GA, USA) and the Intromit (Medtech Ltd, Dublin, Ireland). The HandPort (Smith & Nephew, Andover, MA, USA) also had a sleeve, but the base was held on the abdomen with inflatable compression rather than adhesion. None of these devices remains in production. Lessons learned through their use, however, prompted the development of the improved devices that did not require a separate sleeve.

There are two commercial devices for HALS currently available. The Gelport® (Applied Medical, Rancho Santa Margarita, CA; USA; Figure 76.1) has two components that fit together on the abdomen, affixed by compression and providing gas occlusion with a gel that fits snugly around the surgeon's forearm. The Dextrus™ Access Port (Ethicon Endo-surgery, Cincinnati, OH, USA; Figure 76.2) replaced the Lap Disc®, which was of similar design. It also has two components and is also held within the abdominal incision by compression, but the gas occlusion is achieved with an iris valve that closes around the surgeon's forearm. A final second-generation device, the Omniport (Advanced Surgical Concepts, Wicklow, Ireland), was a cylinder that inflated to provide both abdominal fixation and gas occlusion; it is no longer manufactured.

Gelport®

The Gelport® kit contains the Alexis® wound retractor, which is a pair of plastic rings connected by a flexible skirt that holds the abdominal incision open and provides the base for the second component, and the Gelseal® cap, which snaps onto the outer ring of the wound retractor to provide a gas-tight seal through which a hand or laparoscopic ports can be placed. The abdominal incision is made initially, and then the flexible ring of the wound retractor is inserted into the abdomen, leaving the rigid ring outside (Figure 76.3). The outer ring is rotated inward to shorten the skirt and pull the rings tight against the abdominal wall (Figure 76.4). Once the gel cap is snapped onto the outer ring, the abdomen is gas tight (Figure 76.5). The gel expands enough to allow insertion of a hand through its central slit (Figure 76.6), but also will occlude the incision with nothing passing through it. In addition, ports can be

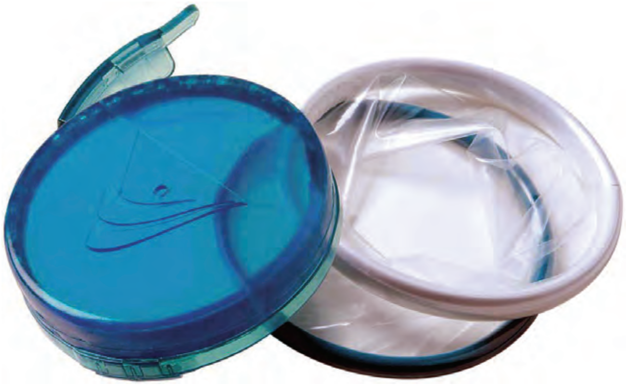

Figure 76.1 Gelport® (courtesy of Applied Medical, Rancho Santa Margarita, CA; USA).

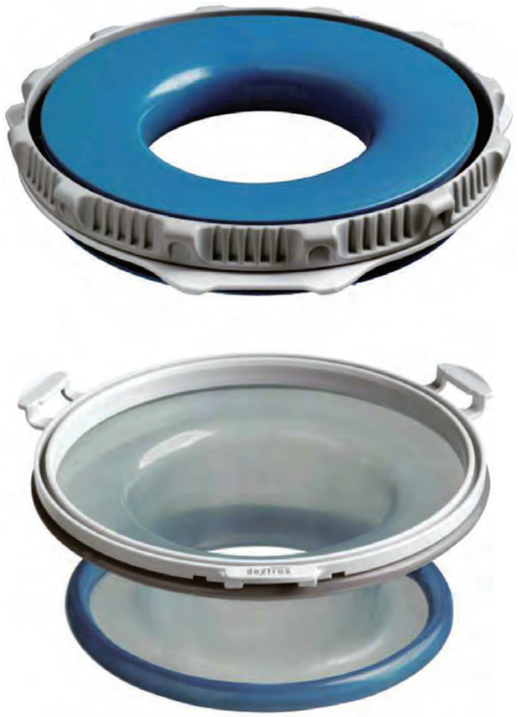

Figure 76.2 Dextrus™ Access Port (courtesy of Ethicon Endo-Surgery, Cincinnati, OH, USA).

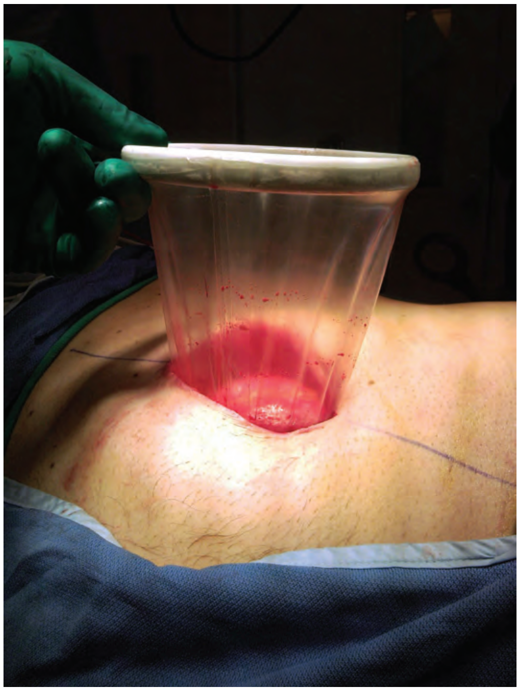

Figure 76.3 Gelport® kit: the flexible ring of the Alexis® wound retractor is inserted into the abdomen, leaving the rigid ring outside.

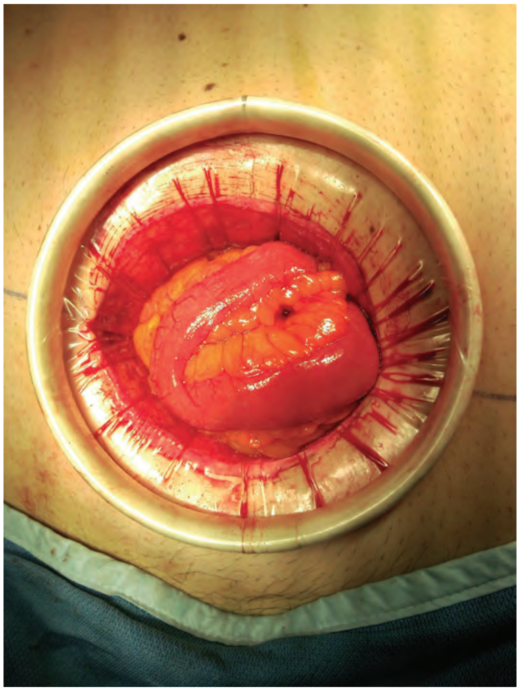

Figure 76.4 Gelport® kit: the outer ring is rotated inward to shorten the skirt and pull the rings tight against the abdominal wall.

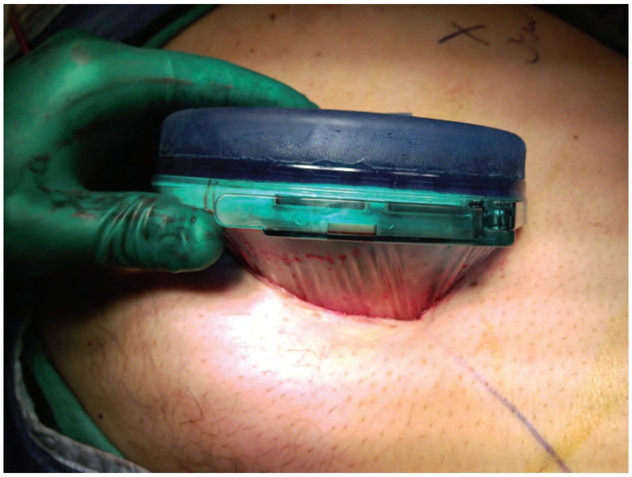

Figure 76.5 Gelport® kit: the gel cap has been attached, and maintains pneumoperitoneum even without the hand through the device.

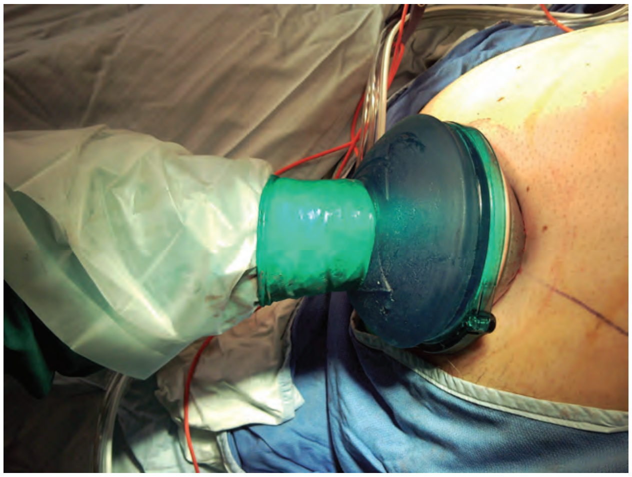

Figure 76.6 Gelport® kit: the intra-abdominal hand is inserted through the central slit of the gel cap.

passed through the central slit in the gel, or through a separate stab incision in the gel (Figure 76.7). An instrument can be passed through the gel alone, or when the hand is in place.

Dextrus® Access Port

The Dextrus® Access Port also is a two-piece device. The base is a fixed length wound retractor comprised of an inner flexible ring and an outer rigid ring connected by an elastic skirt that holds the abdominal incision open and provides the base for the second component. The outer cap is a pair of locking rings that snap onto the base and close an iris valve to provide gas occlusion. The fixed length wound retractor, which is available in three sizes to accommodate abdominal walls of varying thickness, is inserted into the abdomi-

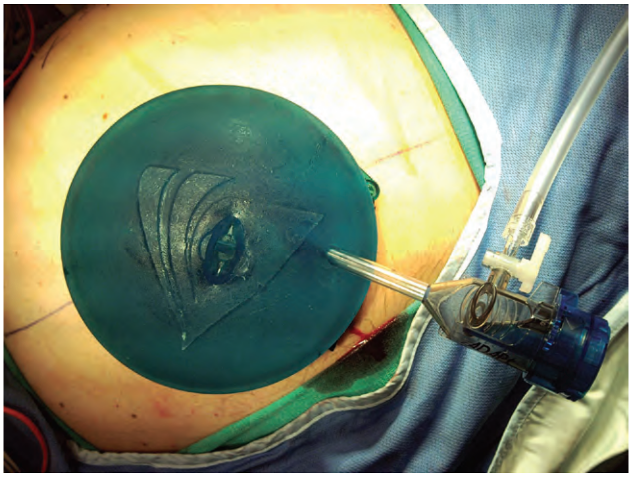

Figure 76.7 Gelseal® kit: a laparoscopic port can be passed through the gel cap.

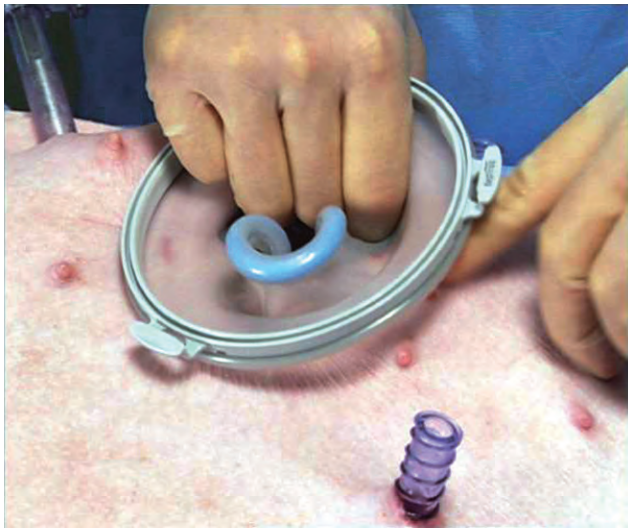

Figure 76.8 Dextrus® Access Port: the wound retractor is inserted into the abdominal incision by slipping the flexible inner ring inside the abdomen (courtesy of Ethicon Endo-Surgery, Cincinnati, OH, USA).

nal incision by slipping the flexible inner ring inside the abdomen (Figure 76.8), with the tension from the elastic sheath holding the rigid outer ring stable on the abdominal wall (Figure 76.9). The outer cap is then snapped onto the wound retractor. To use a hand intra-abdominally, it is inserted to the desired depth and the iris valve is tightened around the forearm by turning the outermost ring clockwise and fixing it in place by way of ratcheted teeth (Figure 76.10). Slight inward movements of the forearm can be made, but large movements require that the iris valve be opened a bit. Similarly, pulling back or removing the forearm necessitates tightening the valve to prevent gas leak. The valve can be completely occluded (Figure 76.11) or it can be tightened around a port or laparoscopic instrument.

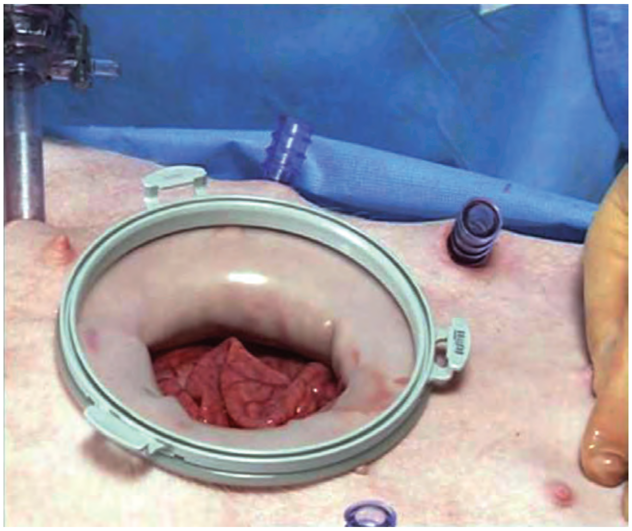

Figure 76.9 Dextrus® Access Port: Tension from the elastic sheath holds the rigid outer ring of the wound retractor tight on the abdominal wall (courtesy of Ethicon Endo-Surgery Cincinnati, OH, USA).

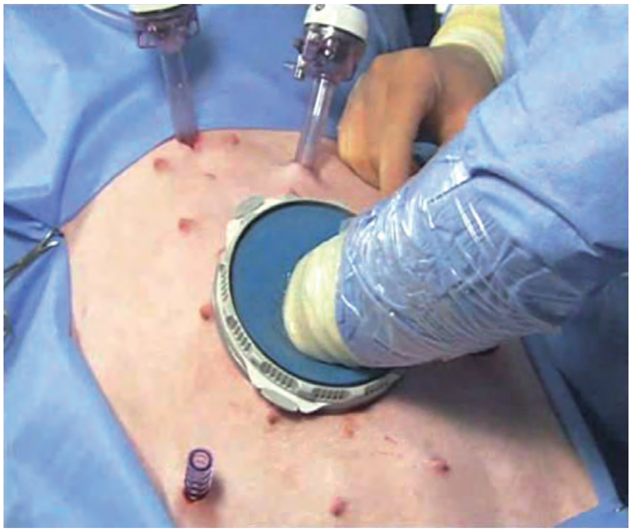

Figure 76.10 Dextrus® Access Port: the iris valve is tightened around the forearm to provide gas occlusion (courtesy of Ethicon Endo-Surgery Cincinnati, OH, USA).

Adjuncts

Fluid can track up the intra-abdominal forearm and soak through the surgeon's gown above the glove. Double gloving does not necessarily prevent this, and some additional barrier is recommended. We have found the simplest and most effective to be a Steri-Drape™ Small Towel Drape 1000 (3M Company, St

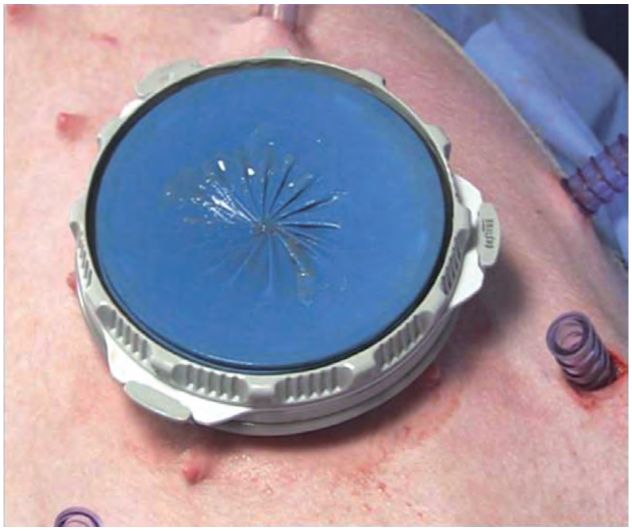

Figure 76.11 Dextrus® Access Port: the iris valve can be completely occluded (courtesy of Ethicon Endo-Surgery Cincinnati, OH, USA).

Paul, MN, USA). The adhesive strip is wrapped around the wrist and the rest of the drape trails down over the forearm, covered by a second glove over the hand and adhesive strip (Figure 76.6). The second glove should be dark to minimize glare. The Dextrus™ Access Port comes packaged with a plastic wrap that serves the same function. Other surgeons have overcome the fluid problem by using a disposable fluid-impervious gown.

Surgical instruments can be placed into the abdomen for use by the intra-abdominal hand. Small open surgical instruments, including Atson forceps and short Satinsky clamps, have been used intra-abdominally during HALS. Of these, the most useful may be hand-held bulldog clamps for temporary vascular occlusion. Additionally, there are instruments made specifically for use by the intra-abdominal hand. The Dextrus™ Finger Mounted Instruments (Ethicon Endo-surgery) fit over the index or middle finger (Figure 76.12), and include Russian forceps, locking forceps, specialty grasper, curved dissector, and spatula retractor (Figure 76.13).

General techniques for hand-assisted laparoscopy

Choice of position for surgeon, HALS device, and ports

Although the application of HALS to retroperitoneoscopic surgery has been reported, it is not a widely accepted technique. This section, pertaining to technique, will not address retroperitoneoscopic HALS, although the few reported series are included in the section on results.

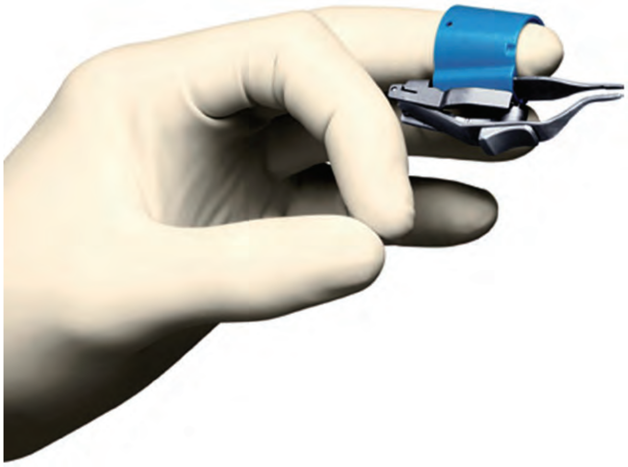

Figure 76.12 Dextrus™ Finger Mounted Instruments fit over the index or middle finger (courtesy of Ethicon Endo-Surgery, Cincinnati, OH, USA).

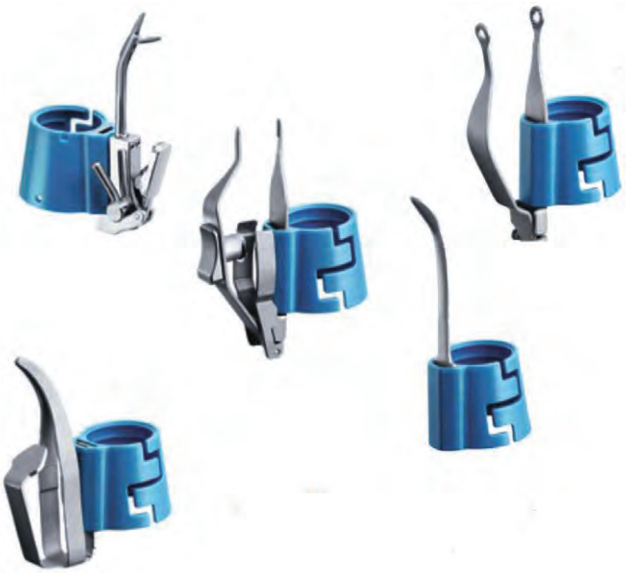

Figure 76.13 Various Dextrus™ Finger Mounted Instruments (courtesy of Ethicon Endo-Surgery, Cincinnati, OH, USA).

Either the primary or the assistant surgeon can use their hand intra-abdominally. When the primary surgeon's hand is intra-abdominal, direct manual dissection is possible. However, the primary surgeon then has only one hand free to manipulate a laparoscopic instrument. If the assistant's hand is in the abdomen, then the primary surgeon can use two laparoscopic instruments, and the intra-abdominal hand is used primarily only for retraction. This distinction is important because it can alter port placement. Figure 76.14 indicates the most common HALS device and port arrangements for HALS renal surgery when the surgeon's hand is intra-abdominal. Figure 76.14A is the most typical arrange-

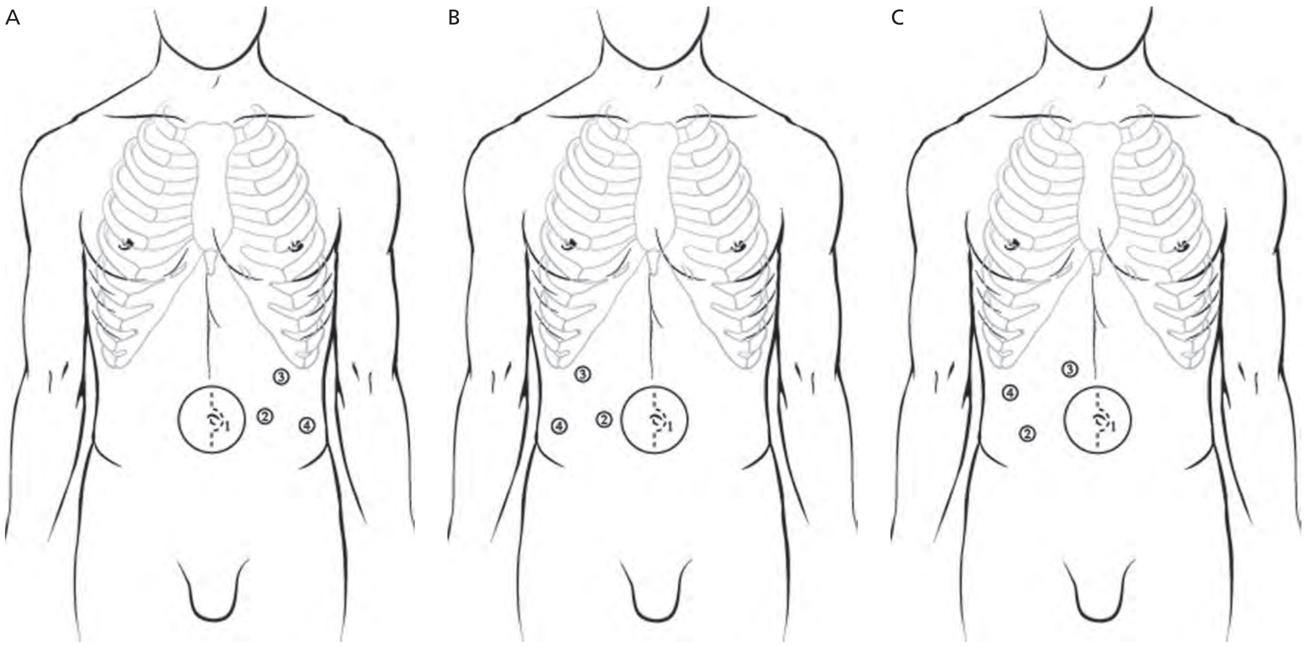

Figure 76.14 (A) Typical port placement for left hand-assisted laparoscopic surgery (HALS) nephrectomy using the surgeon's left hand in the abdomen. (B) Mirror image, for right HALS nephrectomy using the surgeon's right hand in the abdomen. (C) One alternative for right HALS nephrectomy using the surgeon's left hand in the abdomen. 1, HALS device; 2, videolaparoscope port; 3, working port for surgeon; 4, assisting port.

ment for left-sided renal surgery by a right-handed surgeon. The nondominant (left) hand is placed through the HALS device in the periumbilical midline. This allows simultaneous retraction of bowel and finger dissection of the kidney. The assistant operates the videolaparoscope through a port at the level of the umbilicus, 1–2 cm lateral to the edge of the HALS device (#2 in Figure 76.14A), and an instrument placed through a lateral assisting port (#4 in Figure 76.14A). The surgeon's working port is placed 1–2 cm below the costal margin (#3 in Figure 76.14A), on the line that extends from the videolaparoscope port to the patient's ipsilateral shoulder. There is more variation for right-sided renal surgery by a right-handed surgeon. Some, including this author, recommend an arrangement that is the mirror image of the left-sided procedure (Figure 76.14B). The right hand is used intra-abdominally, which allows retraction of the liver by the back of the hand while dissecting the kidney. The surgeon's left hand is used to manipulate laparoscopic instruments, which some right-handed surgeons find awkward. The ability to use either hand intra-abdominally is valuable, and if an "ambidextrous" approach is used when starting out with HALS, then it is quickly learned. Some portions of the procedure are facilitated by using a different hand in the abdomen, on either side, so it is helpful to be ready to use either hand intra-abdominally.

An alternative for right nephrectomy by a right-handed surgeon is depicted in Figure 76.14C. Here, the surgeon's left hand is placed through the HALS device and the right hand operates an instrument through the working port (#3 in Figure 76.14C). The assistant operates the videolaparoscope (#2) and an assisting instrument (#4). Some place the HALS device obliquely in the ipsilateral lower quadrant when using this approach. A number of HALS device placements have been described, including midline (supra-, peri-, and infra-umbilical), paramedian, subcostal, lower quadrant oblique ("muscle-splitting" Gibson incision), and transverse suprapubic (Pfannenstiel). Each will be associated with slightly different port placements, depending on whether the intra-abdominal hand is the surgeon's or assistant's, and whether the left or right hand is preferred. The general principles that guide device and port placement in HALS are: maximization of effectiveness of the hand, minimization of videolaparoscope obstruction by the hand, and centering the videolaparoscope between instruments rather than working with the hand and instruments all off to one side. Use of a 30° videolaparoscope is very useful during HALS to reduce obstruction of vision by the intra-abdominal hand.

Tips and tricks

HALS facilitates transfer of skills from open surgical to laparoscopic surgery. While this is an easier step to make than that from open surgery to standard

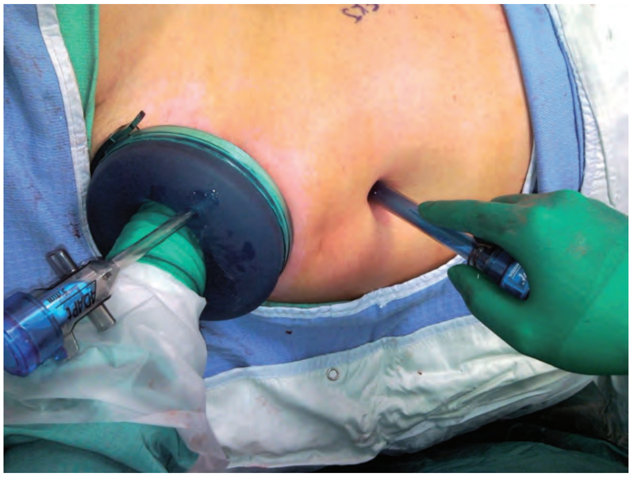

Figure 76.15 Insertion of a laparoscopic port directly onto the intra-abdominal hand.

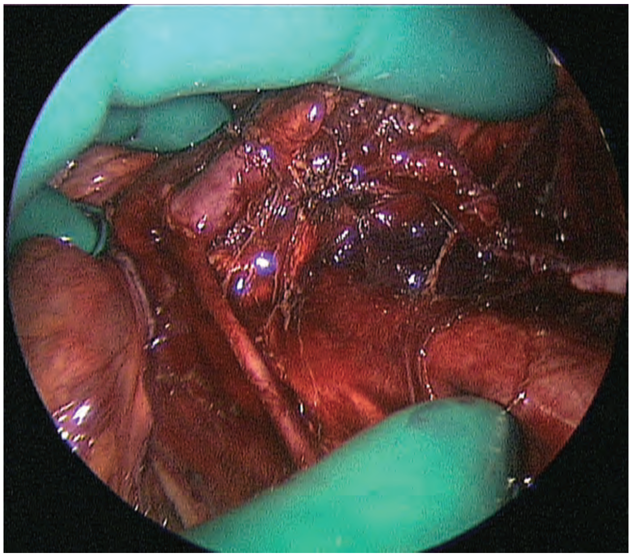

Figure 76.16 The "C" position. Left hand placed through a midline HALS incision, for left nephrectomy.

(nonhand-assisted) laparoscopic surgery, HALS does require a distinct skill set. In this section, some techniques that are different from open surgery and from standard laparoscopic surgery are highlighted.

A laparoscopic port can be inserted through both the Gelport® and the Dextrus® Access Port, and the Gelport® will accommodate several ports or a hand and additional ports. This allows inspection of the abdomen laparoscopically before port placement. Ports can be inserted under direct visualization, or a hand can be placed through the HALS device and the ports can be inserted directly onto the intra-abdominal hand (Figure 76.15). This maneuver should be performed only with noncutting trocars and only after visual inspection has confirmed the inner abdominal wall to be free of adhesions.

After placing the HALS device and ports, a laparotomy pad is placed into the abdomen. This can be used to soak up fluid and blood, either by itself (when it is not yet saturated) or by compressing it with the hand and using a laparoscopic aspirator to remove fluid through the pad. Some surgeons place a hemostat on the blue tag of the laparotomy pad to prevent its complete placement into the abdomen. We prefer to place the entire pad inside the abdomen to allow its unrestricted use, but we do cut off the blue tag and instead clamp it to the drapes as a visual reminder that a pad is inside the abdomen.

Performing multiple tasks simultaneously with the intra-abdominal hand takes greatest advantage of its presence. Retraction and exposure can be obtained in several directions at once, or the hand can simultaneously retract and dissect. One of the most useful multitasking hand positions is the "C" position (a term coined by Stephen E. Strup MD) for dissection medial to the lower pole of the kidney and at the renal hilum (Figure 76.16). Using the left hand for left renal surgery, or the right hand for right renal surgery, the forearm is placed parallel to the great vessels, palm lateral, wrist flexed 45–90°, index finger lifting the kidney, thumb exerting inferomedial traction on tissue, and the middle fingers extended. This position allows simultaneous retraction of bowel with the back of the hand, elevation of the lower pole, and dissection with the fingers. When the hand is elevating the lower pole, an irrigator–aspirator probe or some other instrument can be placed through an assisting port to help in the dissection.

When dissecting out the renal hilum, the renal artery and vein can be encircled *en bloc* with the thumb and forefinger of the intra-abdominal hand. After sharply dissecting tissue cephalad to the renal vein, it is usually easy to bluntly place the index finger cephalad to the renal vein, wiggle it in a posterior direction until the psoas muscle is touched, and then scoop inferiorly to gather up the entire renal hilum. This maneuver is safe as long as a careful touch is used, sensing resistance that indicates an early branch or an accessory vessel. Encircling the hilum in this way provides the ability to rapidly control it in case of vascular injury, and with this added confidence the subsequent hilar dissection can proceed rapidly. This maneuver is less useful if the intention is to remove the adrenal gland with the specimen (on the left side), as it is not safe to perform blunt dissection medial to the adrenal gland.

Results of hand-assisted laparoscopic surgery

Series

In urology, HALS is most commonly applied to nephrectomy. The first reported use of HALS in urology was for radical nephrectomy [4], as was the first use of a commercial HALS device in urology [8]. In one of the earliest large series of HALS for radical nephrectomy, Stifelman *et al.* reported 95 HALS radical nephrectomies for large specimens [11]. The mean operative time was 158 min and the major complication rate was only 4%, with a rate of conversion to open surgery of 3%. The oncologic efficacy of HALS radical nephrectomy has been confirmed in several series with long-term follow-up. Bandi *et al.* reported 5-year recurrence-free survival of 90% after 65 HALS radical nephrectomies with more than 3-year follow-up [12]. Harano *et al.* reported a 4-year recurrence-free survival of 88% in a series of 96 patients [13]. At the University of Michigan, the 5-year recurrence-free survival in a series of 108 patients with a mean tumor size of 6.9 cm was 82% [14]. Kawauchi *et al.* reported a 5-year recurrence-free survival of 92% among 123 patients [15]. In the largest series reported to date of HALS radical nephrectomy with long-term follow-up, a multi-institutional series from 26 centers in Korea involving 197 patients, the 5-year recurrence-free survival was 95% [16].

There have been 17 series (containing 10 or more patients) of HALS nephroureterectomy for upper tract urothelial neoplasms (not including series that have been updated by subsequent ones) published through 2009 [17–33]. In the total of 621 patients described in these series, the operative time averaged 261 min, with 7% major and 14% minor complication rates overall. Conversion to open surgery was required in only 2.5% of cases. The nonvesical recurrence rate was 11% with 23-month mean follow-up. A description of the long-term outcome of HALS nephroureterectomy for urothelial carcinoma from the University of Michigan includes 62 patients with a median follow-up of 77 months: the 5-year cancer-specific survival was 89% for low-grade disease and 72% for high-grade disease [34].

Many of the recently reported series of donor nephrectomy have been with HALS. Among the 12 such series containing 100 or more patients, reporting 2034 patients in total, the mean operative time was 182 min and the mean warm ischemia time 2.1 min [35–46]. The minor and major complication rates were 8.8% and 3.8%, respectively, with a conversion to open surgery in only 1.0% of patients. In the studies that reported convalescence, the mean time to return to nonstrenuous activity levels was 24 days. Graft function has been excellent, with 97.1% functioning at a mean follow-up of 16 months. Delayed function of the allograft occurred in 4.3% and ureteral complications occurred in 2.0%. Of the first 200 HALS donor nephrectomies performed at the University of Michigan, the ureteral complication rate has been 4% [38]. The 1-month, 1-year, and 3-year actuarial graft survival rates are 97%, 95%, and 94%, respectively.

Other reports of HALS for renal surgery include partial nephrectomy [47–51], heminephrectomy (horseshoe kidneys, duplicated upper tracts, etc.) [52–55], bilateral nephrectomy [56–64], and bilateral partial nephrectomy [65]. Bilateral nephrectomy for autosomal dominant polycystic kidney disease is particularly challenging with standard laparoscopic techniques, and is perfectly suited to HALS. Other difficult maneuvers, such as radical nephrectomy with associated excision of renal vein or vena caval thrombus [66–70], and removal of kidneys with xanthogranulomatous pyelonephritis or other inflammatory or unusual conditions [68, 71–76], are facilitated by HALS.

HALS in urology is most commonly applied to renal surgery, but there have been reports of its use for other organs as well. Similar to its use for bilateral nephrectomy, HALS facilitates multiorgan removal for other entities [77–80]. Laparoscopic adrenalectomy is usually well-performed with standard transperitoneal or retroperitoneoscopic techniques, but in cases of large specimens or as an alternative to conversion to open surgery, HALS does have a role in the management of adrenal disease [81–85]. Minimally invasive cystectomy is growing in popularity. Even when using standard or robot-assisted techniques, many surgeons prefer to create at least part of the urinary diversion via a mini-laparotomy. Given this, several groups have reported using this mini-laparotomy incision for a HALS device, and performing the cystectomy or pelvic exenteration with HALS techniques [86–91]. HALS for other procedures, such as ureterolysis [92], retroperitoneal lymph node dissection [93], and resection of local renal cell carcinoma recurrences [94], has been described.

Comparisons to other techniques

Although HALS has been reported via the retroperitoneoscopic route for renal surgery [20, 28, 31–33, 95–101], this is not yet a commonly accepted technique. As such, when assessing the role of HALS in urologic laparoscopy, this chapter considers it to be a transperitoneal approach. Transperitoneal HALS, standard transperitoneal laparoscopy, and standard retroperitoneoscopy all have advantages and disadvantages. In this section, comparisons between the techniques are presented.

Wolf *et al.* reported the initial comparison of hand-assisted and standard transperitoneal laparoscopic nephrectomy in 1998, using the first hand-assisted (n = 13) and standard (n = 8) transperitoneal laparoscopic nephrectomies performed at the University of Michigan and the University of Wisconsin [102]. The mean operative time for hand assistance was 90 min shorter than that for standard laparoscopy. This comparison suggests that early in a surgeon's experience, HALS "shortens the learning curve" for transperitoneal nephrectomy. A subsequent report from the University of Michigan made the same comparison after more experience had been gained, and revealed that after an experience of approximately 20 laparoscopic radical nephrectomies, the advantage of HALS over standard laparoscopy in terms of operative time fell to only 30 min [103].

Two meta-analyses of studies comparing HALS and standard laparoscopic approach for nephrectomy produced similar results. Kokkinos *et al.*, in their meta-analysis limited to donor nephrectomy, evaluated nine studies reporting on 376 patients [104]. They found that HALS and standard laparoscopy had similar donor and recipient complication rates, but that HALS was associated with shortened operative and warm ischemia times, as well as decreased intraoperative bleeding. Silberstein and Parsons assessed the literature 2 years later and considered all types of nephrectomies, and included 25 studies comprising 3051 patients [105]. They found that hand-assisted nephrectomy was associated with significantly less operative blood loss and decreased risk of conversion, but that there were no significant differences in operative time, length of stay, or risk of perioperative transfusion or complication.

In a randomized trial of HALS versus standard donor nephrectomy (20 in each group), Bargman *et al.* found that operative time was significantly less with the standard approach (219 vs 200 min, $P = .02$), but that there were no differences in estimated blood loss, warm ischemia time, length of postoperative stay, analgesic use, rate of complications, pain scores on postoperative day 1 and 2, or quality-of-life scores at 1 and 3 months [106]. Of note, all nephrectomies in this series were performed by a surgeon with extensive experience in both HALS and standard laparoscopy, including more than 100 laparoscopic donor nephrectomies and more than 500 other laparoscopic renal operations prior to the study period. This is consistent with the data reported above; with experience some advantages of HALS over standard laparoscopy (such as in reducing operative time) diminish.

There have been two prospective trials involving HALS for radical nephrectomy. Nadler *et al.*, in a comparison of standard transperitoneal, standard retroperitoneal, and HALS (11 in each group; not randomized but prospectively enrolled in alternating fashion) found that operative time was significantly lower in the HALS group, and that hospital stay and time to normal daily activity were significantly shorter in the standard transperitoneal group [107]. Intraoperative blood loss, postoperative narcotic use, and time to oral intake were similar in all three groups. Although there were no differences in early complications, incisional hernias occurred only in the HALS group. In a multi-institutional randomized trial comparing HALS (nine patients) versus standard transperitoneal laparoscopic (12 patients) radical nephrectomy, Venkatesh *et al.* found no differences in operative time [108].

As noted above, series of surgeons' early experience with standard laparoscopic and HALS nephrectomy often suggest an overall lower complication rate with HALS [102, 109], but as experience is gained the overall complication rates of the two approaches are similar. However, the intra-abdominal hand does appear to reduce some specific complications, in particular the need to convert to open surgery. Silberstein and Parsons found this in their meta-analysis [105]. At the University of Michigan, 196 standard laparoscopic radical nephrectomies were compared with 154 HALS radical nephrectomies [110]. There were no conversions to open surgery from HALS but conversion to open surgery occurred in the standard laparoscopic group in 0.8% of nonobese, 3.0% of obese, and 17% of morbidly obese patients. The difference was statistically significant in the latter two groups. In addition, the availability of HALS provides an alternative to conversion from standard laparoscopy to open surgery; converting to HALS from standard laparoscopy may allow the procedure to be completed in a minimally invasive fashion [111].

Conversely, some complications appear to occur more commonly in association with HALS compared to standard laparoscopy. Troxel and Das noted a 6% rate of incisional herniation at the HALS site in a series of 50 HALS radical nephrectomies [112]. Terranova *et al.* reviewed 54 patients undergoing HALS renal surgery, and reported complications related to the HALS incision in 9.3%, including infection, herniation, skin incisional breakdown, fascial dehiscence, and enterocutaneous fistula [113]. Montgomery *et al.* reviewed 424 consecutive HALS renal procedures and reported similar findings, including infection in 6.8%, incisional hernia in 3.5%, and fascial dehiscence in 0.5% of HALS incisions [114]. Although direct comparative data are limited, some reports suggest an increased wound complication rate with HALS compared to standard laparoscopy [107]. Overall, wound infections and hernias appear to occur less frequently in association with HALS than with open surgery, but more often than in association with standard laparoscopy. In one literature compilation which included 56 reports, there was a significantly greater wound complication rate associated with HALS compared to standard laparoscopy (1.9% vs 0.2%, $P < .05$) [115].

Data comparing the duration and intensity of convalescence after HALS compared to standard laparoscopy are less consistently reported than more objective outcomes, and are subject to bias in retrospective studies. In both of the prospective trials involving HALS for radical nephrectomy described above, there was some measure of a longer and/or more intense recovery period in the HALS patients. Nadler *et al.* found the hospital stay to be 2.1 days after standard transperitoneal laparoscopy compared to 3.4 days after HALS radical nephrectomy [107]. Narcotic use tended to be less in the former group, but the difference was not significantly different. In their multi-institutional randomized trial comparing standard transperitoneal laparoscopic and HALS radical nephrectomy, Venkatesh *et al.* found a significantly longer time to return to normal activity and to work in the HALS group, although there were no differences in hospital stay or narcotic use [108]. In a retrospective but large comparison of the two approaches to radical nephrectomy (113 standard laparoscopic, 158 HALS), Matin *et al*. did find longer hospital stay (4 vs 2 days) and more narcotic use in the HALS group [116]. In another retrospective but large study (147 standard laparoscopic and 108 HALS), Gabr *et al.* found that hospital stay was longer (by a mean of 0.4 days) and time to return to nonstrenuous activity was greater (by a mean of 3.1 days) in the HALS group [110].

In addition to patient-related outcomes, HALS appears to have a distinctive surgeon-related impact. Johnson *et al.*, describing a survey of 25 urologists involved in laparaoscopic fellowship programs, reported that HALS was associated with significantly more hand/wrist, forearm, and shoulder pain compared to standard laparoscopy [117]. Conversely, there was significantly more neck pain associated with standard laparoscopy. There was no significant difference between the approaches in terms of lower back pain. Gofrit *et al.* found similar results in a survey of 73 members of the Endourology Society [118]. HALS was associated with more pain involving the fingers, hand/wrist, and forearm/elbow than standard laparoscopy, while standard laparoscopy was associated with more complaints about neck pain. There were no major differences with regards to shoulder, upper back, and lower back pain. This survey also included questions about robotic surgery. Overall, robotic surgery was associated with the fewest complaints of pain and HALS was associated with the most. The work of Ost *et al*. suggests one possible mechanism for the increased hand, wrist, and forearm pain with HALS [119]. These investigators used oxygen sensors to measure oxygen saturation in the hand during HALS nephrectomy, and found that a report of hand pain during HALS nephrectomy was associated with hypoxia of the hand, down to 56–88% local oxygen saturation.

Overall, then, published data suggest that HALS is generally faster than standard transperitoneal laparoscopy, but that the difference decreases with increasing surgeon experience. The relative impact of HALS on operative time also appears to vary with the specific procedure. For advanced procedures, HALS appears to reduce the likelihood of conversion to open surgery, and converting to HALS is a good alternative to converting to open surgery when standard laparoscopy cannot be continued. There are important disadvantages of HALS to be acknowledged. The larger incision for HALS is associated with rates of infection and herniation that probably exceed those for standard laparoscopy. The intensity and duration of postsurgical recovery is slightly greater with HALS compared to standard laparoscopy, although the magnitude of the difference between HALS and standard laparoscopy is much less than that between HALS and open surgery. Finally, the surgeon pays a price during HALS in terms of increased upper extremity pain compared to standard or robot-assisted laparoscopy.

Selective use of hand-assisted laparoscopic surgery

Table 76.1 lists the advantages and disadvantages of HALS. The relative impact of these considerations differs by surgeon and procedure. Table 76.2 suggests the general situations in which HALS is most useful. HALS is an excellent choice when intact specimen removal is required, as it takes advantage of the required incision throughout the entire procedure rather than just at the conclusion. Another major consideration is surgeon experience, with laparoscopy in general or with

Table 76.1 Advantages and disadvantages of hand-assisted laparoscopic surgery compared to standard laparoscopy.

Typical advantages
Faster
Easier
More control in operating room by surgeon
Better control of vascular injury
Reduced need for conversion to open surgery
Enhanced teaching
Typical disadvantages
Larger incision
Sometimes necessitates suboptimal port placement
Hand can get in the way
Increased wound complication rate
Slightly greater intensity and duration of convalescence
More upper extremity pain for surgeon

Table 76.2 General situations in which hand assistance is most useful.

Intact specimen removal is required

Limited experience:
- With laparoscopy in general
- With specific procedure

Difficult procedure
- Large specimen
- Reoperation
- Perihilar mass that limits access to vasculature
- Other process (inflammation, fibrosis, etc.) that render dissection difficult

Medical comorbidities necessitate rapid procedure

a new procedure. HALS is an excellent way for an inexperienced surgeon to start performing laparoscopy, or for an experienced surgeon to start performing a new procedure. Similarly, a difficult procedure is a good indication for HALS. Large specimens, reoperation, a perihilar mass, or anytime the surgical planes or tissue identification are indistinct can result in a prolonged and complication-prone laparoscopic procedure. HALS can make the difference between conversion to open surgery and completion of the minimally invasive procedure. Finally, for a patient with severe chronic obstructive pulmonary disease or congestive heart failure, in whom a rapid procedure is necessary because of problems owing to hypercapnia or elevated intra-abdominal pressure, HALS can be very useful.

With these considerations in mind, HALS is best selected when there is a clear advantage (in terms of operative time, safety, specimen manipulation, etc.) over standard laparoscopic techniques. The degree of advantage or disadvantage of HALS is determined by the individual surgeon. The best procedures for HALS are advanced extirpative renal procedures. For radical nephrectomy, HALS has most advantage when the specimen is large or the anatomy is difficult. For partial nephrectomy, HALS might facilitate accurate resection, collecting system repair, and/or hemostasis for tumors that are hard to access. For straightforward radical nephrectomies, and for partial nephrectomy for accessible tumors, standard transperitoneal or retroperitoneal techniques are effective in the hands of many. During procedures where intact specimen removal is required, such as nephroureterectomy for urothelial carcinoma or live donor nephrectomy, HALS takes advantage of the required incision throughout the entire procedure rather than just at the conclusion.

For some procedures HALS is less useful, or may even be a hindrance. Laparoscopic simple nephrectomy can be performed in a straight-forward manner with standard transperitoneal or retroperitoneal techniques unless the specimen is inflamed (i.e. pyonephrosis or xanthogranulomatous pyelonephritis) or very large (i.e. autosomal dominant polycystic kidney disease). Standard laparoscopic techniques are also adequate for renal cyst resection and adrenalectomy in most cases. For reconstructive procedures such as laparoscopic pyeloplasty or nephropexy, there is little advantage to HALS. Although there has been some interest in HALS for pelvic procedures, most urologists use a standard or robot-assisted laparoscopic approach to minimally invasive pelvic surgery.

Conclusions

HALS is technically easier than standard laparoscopy, with a "shorter learning curve" for most procedures. The current devices are easily applied and effective. Although there is considerable variation in port placement, especially with regards to right nephrectomy for right-handed surgeons, the general techniques are standardized. Unless there is extensive laparoscopic experience, HALS offers more rapid operating times and a tendency towards lower need for conversion to open surgery than standard laparoscopy for most extirpative renal procedures. These advantages come at the price to the patient of slightly greater intensity and duration of convalescence, and an increased wound complication rate, compared to standard laparoscopy. The surgeon is at greater risk of suffering upper extremity pain. Given prior experience, HALS offers minimal if any improvement over standard laparoscopy for straightforward renal procedures, reconstructive procedures, and most pelvic procedures. HALS is most useful for difficult extirpative laparoscopic procedures, and when intact extraction is desired.

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CHAPTER 77
Pelvic Lymphadenectomy

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Introduction

Schuessler *et al.* first reported laparoscopic pelvic lymph node dissection (LPLND) for staging of prostate cancer in 1991 [1]. In the early 1990s LPLND was the most frequently performed urologic laparoscopic surgery. With stage migration in prostate cancer observed with widespread screening of patients, LPLND is frequently performed with a radical prostatectomy or, more recently, with cystectomy. The operation provides useful information in a patient with prostate or bladder cancer where pathologic involvement of the pelvic lymph nodes will alter definitive management of the malignancy. Today, although LPLND is most commonly performed for the surgical staging of prostate cancer, indications for an extended version of this staging modality are malignancy of the bladder, urethra, and penis, where confirmation of nodal metastases can significantly alter management.

For patients with urologic pelvic malignancy, the status of the pelvic lymph nodes will have a major impact on prognosis, as well as the determination of appropriate therapeutic intervention. It is generally agreed that any significant lymphatic dissemination of malignancy in a patient with neoplastic disease involving the prostate, urethra, or penis is a sign that the cancer is most likely incurable in most patients. Similarly, the detection of positive pelvic lymph nodes in patients with transitional cell carcinoma (TCC) of the bladder is a poor prognostic finding that should suggest the need for chemotherapy. LPLND can provide important prognostic and therapeutic benefit in the treatment of neoplasms. This underscores the importance of obtaining accurate histopathologic staging information prior to developing a treatment plan.

In the past, attempts at detecting pelvic lymphatic metastases using noninvasive diagnostic modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and pelvic lymphangiography, have been unsatisfactory as a result of unacceptably low sensitivity and specificity, though these are improving with newer detection techniques [2, 3]. Ultrasound- and CT-guided transcutaneous fine-needle aspiration biopsy (FNAB) can be effective when evaluating enlarged pelvic lymph nodes. Unfortunately, the latter two interventions are highly operator dependent, and in the absence of gross lymphadenopathy are incapable of determining the presence of micrometastasis following early dissemination of malignancy. Therefore, PLND remains the gold standard for accurate staging of patients with urologic pelvic malignancy.

Recent lymph node mapping series suggest that some patients may benefit from a more aggressive lymph node dissection [4, 5]. Patients with an increased risk of lymph node metasasis of prostate cancer may be understaged with a limited lymph node dissection [5–10]. In bladder cancer, an extended lymph node dissection increases the rate of detection of positive lymph nodes in several series, providing valuable treatment information [11–13]. In both patients with and without node-positive disease, an extended lymphadenectomy may even provide a survival benefit [12–15].

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Since lymphatic metastasis from primary malignancy involving the prostate and other pelvic organs will have major prognostic and therapeutic implications, the minimally invasive nature of LPLND to detect disseminated and probably incurable disease could potentially circumvent the unnecessary morbidity associated with unsuccessful radical therapy. More often the urologist performs these dissections as part of a larger surgery intended to remove the cancer. With the increase in laparoscopic and robotic prostatectomy and cystectomy, the need to perform an adequate minimally invasive lymphadenectomy has grown. In recent series, the lymph node yield of minimally invasive lymphadenectomy is comparable to that of open lymphadenectomy [16, 17].

In this chapter we review the indications and techniques for minimally invasive pelvic lymphadenectomy.

Indications

Adenocarcinoma of the prostate

In a landmark study in 1959 that evaluated the common lymphatic pathways by which metastatic adenocarcinoma of the prostate spreads, Flocks *et al*. clearly demonstrated a direct correlation between the clinical stage of disease and an increased likelihood of lymphatic metastasis [18]. This was especially true in patients in whom periprostatic extension involved the seminal vesicles; pelvic lymph node metastasis was noted in 50–80% of patients under these circumstances.

Similarly, elevation of serum tumor markers, including enzymatic prostatic acid phosphatase (PAP) and prostate-specific antigen (PSA), may suggest an increased likelihood of lymph node involvement. Stamey and Kabalin have demonstrated a strong correlation between advanced pathologic stage and increasing serum PSA [19]. Similarly, Lange *et al*. and Hudson *et al*. reported studies in 1989 that focused on the correlation between serum PSA and pathologic stage [20, 21]. Based on an analysis of data culled from several studies, Lange *et al*. reported a 65% likelihood of seminal vesicle or lymph node involvement in patients with a preoperative PSA value between 20 and 50 ng/mL (Hybritech assay) [20].

Preoperative prediction nomograms have been developed in an attempt to help guide physicians on which patients are at risk for lymph node involvement. The Partin and Kattan nomograms have 80% accuracy in predicting lymph node metastases [22, 23]. The widespread acceptance of these nomograms is reflected in the 2009 National Comprehensive Cancer Network guidelines which state that patients with a less than 7% risk of lymph node metastasis can forego a formal lymph node dissection [24]. However, these nomograms rely heavily on PSA, biopsy Gleason score, and clinical stage.

Until recently imaging techniques, either CT or MRI, have yielded a 35% sensitivity for detecting lymph node invasion, primarily due to stage migration of prostate cancer, making micrometastases in lymph nodes more prevalent than gross metastases [25, 26]. Pelvic MRI using an endorectal coil may help in detecting smaller lymph node metastases. New innovations utilizing lymphotropic agents, such as paramagnetic iron-oxide nanoparticles and ferumoxtran-10, can increase the sensitivity and specificty to 80–90% and 96–98%, respectively [27, 28]. Additionally, improvements in serum tumor markers have improved the ability to preoperatively predict lymph node invasion. For example, endoglin, a cell-surface protein located in endothelial cells, demonstrated a 98% accuracy in predicting lymph node involvement when combined with clinical stage, biopsy Gleason score, and PSA [29].

Although these important studies have greatly increased the urologist's ability to predict the extent of disease in patients with prostate cancer, the associations are by no means absolute. Unfortunately, the relationship between serum tumor markers and actual pathologic stage is not clear cut. A markedly elevated PSA level is strongly indicative of advanced disease, whereas a PSA of less than 10 ng/mL suggests early local disease. However, to rely on these values alone may lead to an under- or over-staging of prostate cancer , resulting in erroneous therapeutic intervention and unwarranted morbidity with no clinical improvement in the patient's outcome [30]. Furthermore, newer predictive modalities require further investigation to determine their relationship to the clinical outcome of disease. They are also limited in the validation of pathology of the tissue obtained during the PLND, for which there are several variations in the template for dissection. For this reason, histopathologic evaluation of the pelvic lymph node specimen remains the gold standard for making therapeutic decisions [31].

Prognostic and therapeutic impact in prostate cancer

Patients identified to have positive lymph nodes at the time of radical prostatectomy have demonstrated a worse prognosis than those who are not. In a series of over 1400 patients treated with laparoscopic prostatectomy, Touijer *et al*. found a 78% overall 5-year progression-free probability for all risk groups of prostate cancer versus only a 49% 3-year progression-free probability in lymph node-postitive patients, where all patients demonstrated a clinical recurrence within 5 years [32]. In a series of 143 node-positive patients, Palapattu *et al*. noted a 17% PSA progression-free rate at

7 years of follow-up [33]. More specifically, a combined series of 703 lymph node-positive patients following radical prostatectomy with extended PLND demonstated that patients with two or fewer positive lymph nodes demonstrated an improved cancer-specific survival relative to those with more than two positive lymph nodes (84% vs 62% at 15-year follow-up). Patients with more than two positive lymph nodes were 1.9 times more likely to die from prostate cancer [34].

Identification of patients with positive lymph nodes provides prognostic information that is useful in counseling and monitoring patients. It also has the potential to identify high-risk patients who may benefit from adjuvant or salvage therapy. In a retrospective review of 250 consecutive patients with positive lymph nodes, salvage radiation therapy was associated with a hazard ratio (HR) of 0.38, relative to those receiving postoperative hormone therapy alone in multivariate analysis [35]. This result, however, is controversial and requires corroboration in additional studies.

It is also controversial whether pelvic lymphadenectomy can provide a therapuetic benefit in prostate cancer. In a review of 13 000 prostatectomies contained in the Surveillance, Epidemiology, and End Results (SEER) database, pelvic lymphadenectomy was performed in 71% of patients. Cancer-specific mortality decreased in patients in whom more than four lymph nodes were removed (HR 0.77). Furthermore, if more than 10 lymph nodes were removed, cancer-specific mortality also decreased in patients who had negative lymph nodes (HR 0.89) [7]. Similarly, in over 5000 patients reviewed in another series, lymphadenectomy in patients with node-negative disease correlated with a decreased rate of biochemical recurrence [9]. Finally, in 274 T3 patients, 13% of those initially thought to be node negative harbored micrometases and developed recurrence at a rate similar to those with initially diagnosed positive lymph nodes [9].

Although these studies suggest an oncologic benefit of lymphadenectomy for both lymph node-positive and -negative disease, it is unclear whether, by taking an increased number of lymph nodes, the perceived benefit was artificially increased by identifying a lower risk group of lymph node-positive patients and removing more false-negative patients in the negative lymph node patients. In contrast to these studies, two studies found no relationship between lymphadenectomy and patient survival. In 336 low-risk prostate cancers, omission of PLND did not affect biochemical recurrence at 6 years [36]. In over 7000 patients at the Mayo Clinic with a median of nine lymph nodes removed, there was no association between the number of lymph nodes removed and PSA recurrence, systemic progression, or prostate cancer death [37]. Future studies will be needed to determine the effect of lymphadenectomy on prostate cancer outcome.

It has been previously thought that LPLND is most useful in a patient in whom metastatic prostate cancer is detected as this avoids the morbidity of treatment for presumed localized prostate cancer. Conversely, patients who undergo LPLND and do not have nodal metastases have had an unnescessary procedure. Wolf *et al*. used cost and patient preference endpoints in a decision-analysis model, and determined that LPLND before intended radical retropubic prostatectomy was beneficial only in patients with at least a 39% risk of lymph node metastases [38]. More recently, a series by Engel *et al.* challenged the notion that prostatectomy should be avoided in lymph node-positive patients. Among 1400 lymph node-positive patients in a retrospecitve review, those who underwent a radical prostatectomy had an overall survival at 5 and 10 years that was superior to that for patients who did not undergo prostatectomy (84% and 64% vs 60% and 28%). Although there were fewer patients in the prostatectomy group with four or more positive lymph nodes (17% vs 28%), the survival benefit of a radical prostatectomy persisted in a multivariate analysis (HR 2.01), which was independent of the number of positive lymph nodes [34].

Obvious nodal involvement portends poor prognosis following radiotherapy. However, the benefit of LPLND before radiotherapy is not clear. Gerber *et al.* compared the outcome of 31 men with localized prostate cancer and negative LPLND with 42 men with localized prostate cancer who underwent radiotherapy without lymph node dissection. There was no significant difference in follow-up PSAs or development of skeletal metastases between the two groups after controlling for PSA levels, Gleason scores, and clinical stage [39].

Limited versus extended lymphadenectomy

Before 1980 the surgical staging of prostate cancer included a lymph node dissection of all fibrofatty lymph node-bearing tissue within the space bounded by the genitofemoral nerve laterally, the common iliac vessels proximally, and Cloquet's node distally. This extensive lymphadenectomy effectively removed the common and external iliac, hypogastric, and obturator lymph node groups. Unfortunately, the extent of this dissection led to an early complication rate of 12–24%, with patients experiencing lymphocele formation, lymphedema, and thromboembolic phenomena [40]. Over the last 20 years a less extensive lymphadenectomy has been advocated. This modification in the margins of dissection was based on the knowledge that 85–95% of lymph node positivity in patients with lymph node metastases was found within the obturator–hypogastric node packets. Furthermore, the incidence of so-called metasatic skip lesions, which bypass the primary obturator–hypogastric landing zones to involve the more proximal iliac or aortic chains, was reported to be only 6–14% [41, 42]. These findings have led to the standardization of obturator–hypogastric lymphadenectomy as an acceptable procedure for the pathologic staging of patients with prostate cancer.

Currently, much of the debate over PLND in prostate cancer concerns when to do a limited or extended template. The limited template typically is bounded by the medial surface of the external iliac artery anteriorly and the obturator nerve posteriorly. Extended lymph node dissection involves removal of the lymph nodes from the lateral surface of the external iliac artery to the medial surface of the hypogastric artery, extending distally to the origin of the circumflex iliac vessels. There is some variability as to the proximal extent, but it should at least include the bifurcation of the iliac artery, and in some reports includes more of the common iliac nodes (Figure 77.1). Clark *et al.* from Vanderbilt University randomized 123 patients undergoing radical prostatectomy to an extended node dissection on the right versus the left side of the pelvis, with a limited dissection on the other side. The limited dissection only included nodes along the external iliac vein and the obturator nerve. Pelvic nodal metastases were found in eight patients (6.5%). Positive nodes were found in four patients on the side of the extended dissection, in three patients on the side of the limited dissection, and on both sides in one patient. They concluded that extended node dissection in patients undergoing radical prostatectomy identifies few patients with nodal involvement who are not detected by a limited dissection. Complications, which included lymphocele in four patients, lower extremity edema in five, deep venous thrombosis in two, and ureteral injury and pelvic abscess in one each, occurred three times more often on the side of the extended dissection. However, this was a group of patients with a low probability for nodal metastases [43].

The low risk of positive lymph nodes in patients with low-risk prostate cancer (PSA ≤10 ng/mL, Gleason score ≤6, and stage T1c) has been corroborated in other series [44]. With limited lymph node dissection, the incidence of positive lymph nodes did not exceed 1%. Similarly, in series with extended lymph node dissection, the incidence does not exceed 8% for these patients [45]. Thus, the available prostate cancer guidelines do not routinely recommend staging PLND in patients within this low-risk category. This is supported by studies that fail to demonstrate a survival benefit with PLND in these patients [36, 37]. However, these survival studies are based on limited PLND and have a very low death rate overall, which makes comparison difficult.

Recent studies that include a greater number of intermediate- and high-risk prostate cancers suggest that positive lymph nodes can be missed by limitedPLND. In a study of 365 patients who underwent meticulous lymph node dissection along the external iliac vein, the obturator nerve and the hypogastric vessels during an open radical retropubic prostatectomy, positive lymph nodes were found in the nodes along the hypogastric artery in 58% of patients and exclusively at that site in 19% [46]. Eden *et al.* reviewed 374 patients who underwent PLND for PSA of 10 ng/mL or greater or Gleason score of 8 or greater, of which 253 had limited PLND and 121 had an extended lymphadenectomy. Median lymph node removal by a more limited approach (labeled standard in this series) yielded 6.1 nodes versus the extended approach which yielded 17.5 nodes. The limited template had a 0.4% positive lymph node rate, while the extended template had a 5% positive rate [6].

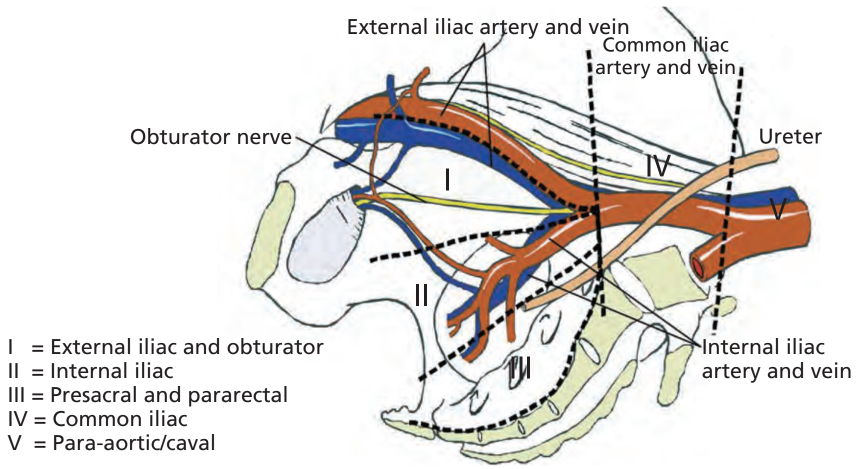
External iliac artery and vein
Common iliac artery and vein
Obturator nerve
Ureter
I
IV
V
II
III
Internal iliac artery and vein
I = External iliac and obturator
II = Internal iliac
III = Presacral and pararectal
IV = Common iliac
V = Para-aortic/caval

Figure 77.1 Lateral view of the pelvic wall shows the regions for pelvic lymph node dissection (reproduced from Mattei *et al.* [5], with permission).

In a series of 32 patients undergoing robotic extended PLND, a median of 18 nodes were removed, and positve nodes were found in 13% of patients [47]. In a series of 163 patients, Polcari *et al.* demonstrated an increase in median node removal and postive lymph node rate with the extended template (14.8 nodes, 18.6%) relative to standard templates performed robotically (8.2 nodes, 3.3%) or in an open fashion (7.6 nodes, 1.6%). Furthermore, the rate of postive lymph nodes increased with Gleason score: 0% for Gleason 6, 7% for Gleason 7, and 24% for Gleason 8 or higher [16]. Among the currently available guidelines for prostate cancer, the European Association of Urology and the National Comprehensive Cancer Network indicate that the use of an extended template is needed for higher risk prostate cancers. The American Urological Association (AUA) also indicates PLND for these patients, but does not specify the template [24].

As was previously suggested, the likelihood of encountering lymphatic metastasis in patients with low-stage/low-grade disease (T1a, T1c, T2a, and/or well-differentiated) is low. In this cohort, if surgical intervention is elected, it is generally considered appropriate to proceed directly to radical retropubic prostatectomy with concomitant PLND. Alternatively, if radical prostatectomy is considered, the minimally invasive nature of LPLND makes it the ideal procedure if pathologic staging is warranted based on preoperative physical examination and laboratory evaluation.

Patients who may be considered for LPLND before definitive treatment of prostate cancer include:

- Clinical stage T2b or higher;
- Gleason scores of greater than 7;
- Serum PSA of ≥20 ng/mL (Hybritech assay);
- Positive seminal vesicle biopsy (T3c);
- Enlarged lymph nodes on pelvic imaging, when percutaneous biopsy was not possible.

As will be discussed later in this chapter, a more extensive pelvic lymphadenectomy is appropriate for staging cancers involving primary sites with a more proximal lymphatic drainage. Although extended lymphadenectomy is usually advocated for the pathologic staging of neoplasia arising in the urinary bladder, urethra, or penis, there are certain clinical situations in which extensive lymph node dissection is also advisable in men with prostate cancer.

Patients with a profoundly elevated serum PSA (≥20 ng/mL) are at an increased risk of demonstrating advanced disease. In these patient cohorts a negative intraoperative histopathologic evaluation of obturator lymph node frozen sections should alert the urologist to the possibility that "skip lesions" involving more proximal lymph node chains may be present. In such instances where clinical and laboratory evidence strongly suggest advanced prostate cancer, but frozen section pathologic studies show the obturator lymph nodes are free of metastatic disease, extended LPLND may be considered.

Carcinoma of the urinary bladder

It has been demonstrated that the perioperative morbidity and mortality following radical cystectomy with concomitant pelvic lymphadenectomy does not significantly differ from that of cystectomy alone. However, this radical approach may improve the accuracy of staging and potentially increase the survival of patients demonstrating micrometastatic nodal disease [48–52]

If during radical cystectomy intraoperative frozen-section evaluation reveals extensive lymphatic metastasis from primary TCC of the bladder, it is advocated that the procedure be terminated and chemotherapy intiated. Similarly, in a patient with lymphatic dissemination of adenocarcinoma or squamous cell carcinoma of the urinary bladder, extirpative surgery is unlikely to have any curative potential. For these reasons, the lymph node status of patients with primary cancer of the urinary bladder can be a major determinant in selecting the optimal therapeutic approach for each individual [40, 48–51].

The urinary bladder has a more proximal primary lymphatic drainage route than the prostate. Thus, standard and extended lymphadenectomy in bladder cancer extend more proximally than those for prostate cancer. At the minimum, Mills *et al.* describe standard lymphadenectomy to include the internal iliac, presacral, obturator, external iliac, and distal common iliac nodes [53]. The boundaries of extended lymph node extension, as defined by Stein *et al.*, include the lymph nodes bound by the node of Cloquet distally, hypogastric vessels posteriorly, the genitofemoral nerve anterolaterally, and the aortic bifurcation proximally [53]. Some describe this extension as far proximal as to the level of the inferior mesenteric vessel, which includes some paracaval and aortic nodes. Recent mapping studies of lymph node metastases during radical cystectomy support an extended dissection. Vazina *et al.* reviewed 43 patients with lymph node metastasis among 176 consecutive patients undergoing radical cystectomy with extended pelvic lymphadenectomy, in which a median of 25 lymph nodes were removed. In pT1 patients, there was one lymph node metastasis, which was in the pelvic lymph nodes. In pT2 patients, two (3%) had postive lymph nodes outside of the pelvis, while four (16%) pT3 patients had metastasis at or above the common iliacs [4]. In a multicenter review, Leissner *et al.* reported a 27.9% positive lymph node detection rate in 290 radical cystectomies with extendedPLND. Of these patients, 20 had pelvic metastasis only in the pelvis, 20 had lymph node metastasis only in the region between the common

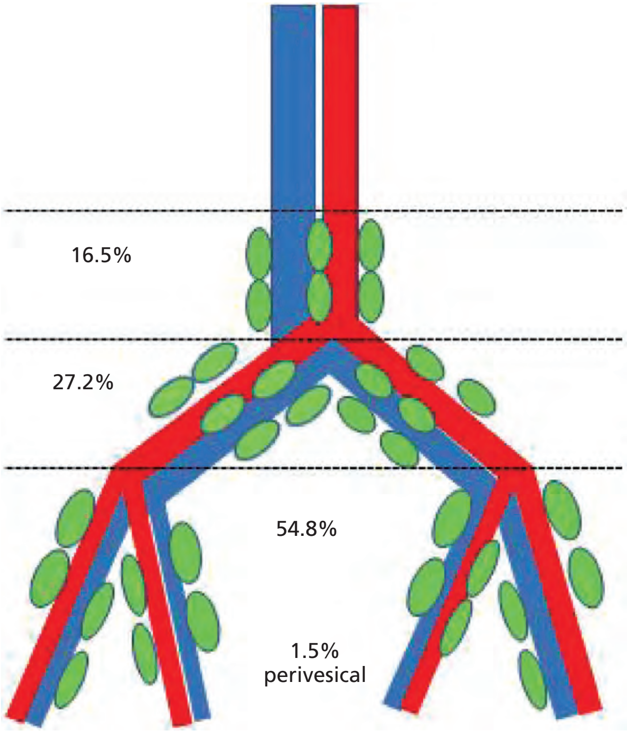

Figure 77.2 Lymphatic drainage levels for bladder cancer. A significant proportion of lymph node metastases present at the level of the common iliacs and bifurcation of the aorta as the only region of metastasis. Lymph node metastases proximal to the bifurcation of the aorta are nearly always found in the presence of more distal lymph node metastases (reproduced from Leissner *et al*. [54], with permission.

iliac and aortic bifurcations (including the presacral nodes), and none had metastasis located only above the aortic bifurcation. However, 16.5% of nodal metastases were located above the aortic bifurcation (Figure 77.2) [54] In the mapping series there were very few reported skip lesions appearing in the para-aortic region without appearing in the more distal regions [55, 56]. Thus, lymphadenectomy is necessary at least up to the point where the ureters cross the common iliac arteries, but bladder cancer probably warrants dissection up to the aortic bifurcation.

In terms of prognostic significance, pelvic lymphadenectomy in the setting of bladder cancer provides strong predictive evidence. Positive lymph nodes at the time of radical cystectomy were found in 67% of 130 pelvic recurrences reported by Dhar *et al* [14], and 128 of the patients with pelvic recurrences died within a median of 4.9 months following the recurrence. The number of positive lymph nodes also has prognostic significance with different series reporting cut-offs of five, six, and eight positive lymph nodes [57–59]. Additionally, the number of lymph nodes removed may provide separate outcomes, ranging from nine to 25 as cut-off values [15]. Lymph node density has been reported in several series to have strong prognostic information. In a review of 10 studies, reporting on 2000 unique patients, the cut-off for lymph node density ranged from 10% to 25%, with most using 20% as a cut-off. Five-year recurrence-free survival for patients with a density less than 20% was approximately 40% versus 15% in those who had a density greater than 20% [60]. Finally, extracapsular extension of the lymph nodes provided the strongest negative predictor in a series of 101 lymph node-positive patients reported by Fleischman *et al.*, with a median overall survival of 16 months compared to 60 months for patients without extranodal extension [61].

In addition to its prognostic utility, PLND may also impact the survival of patients undergoing radical cystectomy for bladder cancer. There have been reports demonstrating that a proportion of patients with grossly node-positive bladder cancer can be cured with radical cystectomy and an extendedPLND [62]. In a study of 84 patients with grossly node-positive bladder cancer (N2–3) who underwent cystectomy and extended PLND, 24% survived with a follow-up of up to 10 years [63].

Leissner *et al.* reported improved recurrence-free survival at 5 years in both lymph node-negative patients with more than 16 lymph nodes removed (organ confined: 85% vs 63%; pT3: 55% vs 40%) and lymph node-positive patients with five or fewer positive lymph nodes (53% vs 25%) [54]. Corroborating the benefit in node-negative, organ-confined patients, Poulsen *et al.* reported a 90% recurrence-free survival in patients receiving extended lymphadenectomy versus 71% in those treated with standard lymphadenectomy [64]. More recently, Dhar *et al.* compared over 300 extended and 300 limited lymphadenectomies, and reported improved survival rates in patients with and without positive lymph nodes in both organ-confined and pT3 disease [14]. Fang *et al.* demonstrated improved outcomes by instituting a minimum 16 lymph node policy on radical cystectomy patients. They compared outcomes over 4 years with the policy against 4 years prior to the policy. With the policy in place, the proportion of cases with 16 or more nodes removed increased from 42.9% to 69.3%, lymph node density less than 20% increased from 43.9% to 65.5%, and overall survival increased from 41.5% to 72.3% [12]. Although several studies suggest an improvement in survival with removal of a larger number of nodes, it is not clear how much of this benefit is due to selection bias. In patients who are deemed node negative in survival analyses, the number of patients who are falsely deemed node negative is reduced by increasing the number of nodes removed. Furthermore, in patients with node-positive disease, more patients with a very small amount of lymph node-positive disease are included in the survival analyses of those with extended lymphadenectomy, leading to an increased survival in the lymph node-positve patients. Also complicating the analysis of lymph node removal is the variability in processing or counting lymph nodes that have been removed. It has been previously demonstrated that lymph node counts increase when the specimen is submitted as separate packets rather than as one *en bloc* specimen [65].

Extended LPLND in patients with TCC of the bladder is therefore likely to be indicated in patients undergoing laparoscopic or robotic cystectomy [66, 67]. Recent series of laparoscopic and robotic cystectomy demonstrate node yields that are similar to those for open PLND. In a review of 278 patients in 12 separate series of robotic cystectomy and pelvic lymphadenectomy, the mean number of lymph nodes removed in series with more than 10 patients ranged from 13 to 25 lymph nodes [68]. In another series, 30 patients undergoing laparoscopic cystectomy with pelvic lymphadenectomy yielded a similar number of lymph nodes as 35 open cystectomies (12 vs 14 lymph nodes, $P = .410$) [69]. Although current comparison of these minimally invasive techniques to open lymphadenectomy are limited, experience with these will likely increase, allowing for a more complete comparison.

Cancer of the urethra

Although exceedingly rare, isolated carcinoma of the urethra is the only urologic cancer more commonly seen in the female population [70]. Tumors involving the distal urethra generally metastasize to the superficial and deep inguinal nodes. More proximal urethral lesions metastasize first to the external and internal iliac, as well as the obturator lymph node chains, although some overlap of the respective drainage fields is not unusual. In several series, lymphatic involvement at initial presentation was as high as 35–50%, foreshadowing a bleak prognosis for patients with this disease. In 80–96% of cases in which palpable inguinal lymphadenopathy was found at the initial assessment, the disease had already metastasized [71].

Because of the rarity of this disease, the management approaches remain the subject of debate among members of the urologic community. As with other genitourinary malignancies, radical exenterative surgery is not indicated in patients with evidence of metastatic urethral carcinoma as the disease course will not be improved and the prognosis at this stage is grim. Extended LPLND may be considered in a select group of patients:

- Present with rRadiologic evidence of pelvic lymphadenopathy that is not accessible to percutaneous needle biopsy;
- Female patients with locally invasive distal lesions (muscle or periurethral tissue invasion) in the face of positive inguinal lymph nodes based on FNAB findings. Those being considered for radiotherapy as a primary modality for urethral cancer.

Cancer of the penis

The superficial and deep inguinal lymph node chains provide the lymphatic drainage for the skin (including the prepuce and frenulum) and subcutaneous tissues of the penis. The corpora cavernosa and spongiosum, urethra, and glans penis drain primarily into the external iliac nodes via the deep inguinal lymphatic chain [72]. In 25% of cases, palpable inguinal lymphadenopathy harboring metastatic disease is present at the time of initial presentation. Pathologic evaluation of bilateral inguinal lymph node dissection specimens from patients presenting with nonpalpable nodes reveals an additional 12–20% of patients with metastatic disease at the time of presentation [73, 74].

The 5-year survival rate of patients with inguinal lymph node metastases who are left untreated is roughly 19%. The prognosis is improved to an approximately 45% 5-year survival rate if an early bilateral ilioinguinal lymphadenectomy is performed, and as high as 84% in patients with microscopic-only positive lymph nodes undergoing early inguinal lymph node dissection (ILND) [75, 76]. This signifies the possibility of surgical cure even in the face of early disseminated disease. Unfortunately, this procedure is not without significant risk. A review of recent series of ILND totaling 390 patients demonstrated a major complication rate ranging from 5% to 37.5% [77]. While imaging studies have poor sensitivity in detecting pelvic lymph node metastases, pathologic information obtained from inguinal lymph nodes can identify patients at increased risk. Patients with extranodal extension, high-grade disease in the lymph nodes, or more than two involved lymph nodes are at increased risk of having positive pelvic lymph nodes [78, 79].

Tumor metastases found within the iliac (or more proximal) lymph nodes are associated with an exceedingly dismal prognosis. In a review of 128 patients undergoing ILND, overall survival at 5 years of patients with positive nodes in the inguinal region only was 64.1%. In contrast, all 21 patients with positive pelvic lymph nodes died within 3 years [79]. Given this dismal prognosis, Mukamel *et al*. recommend that bilateral pelvic lymphadenectomy should be the initial pathologic staging procedure for patients with penile cancer [2]. They described an extended dissection encompassing the removal of all lymphatic tissue from the femoral canal to the bifurcation of the iliac vessels. The boundaries of lymphadenectomy are similar to the dissection with bladder cancer. However, more distal lymphatic dissection should include the perivascular lymphatics overlying the pubic bone and underneath the inguinal ligament [80]. Pelvic lymph node positivity revealed during this procedure would obviate the need for subjecting the patient to the attendant morbidity and mortality of groin dissection, as the probability of obtaining a surgical cure at this point is essentially zero. The therapeutic benefit of complete pelvic lymphadenectomy has not been established. It can, however, provide useful staging information that can identify patients for additional therapy. However, in the event that the pelvic lymphadenectomy reveals no metastasis in the excised tissue, ILND is recommended. For the initial staging of patients with carcinoma of the penis, we recommend extended LPLND in patients with increased risk of pelvic lymph nodal metastases. Risk factors include extensive inguinal nodal involvement, CT evidence of pelvic lymphadenoapathy that is inaccessible to needle biopsy/aspiration cytology, and a high-grade or -stage invasive primary neoplasm. It can be performed with the inguinal lymphadenectomy or it can be staged, depending upon the likelihood and extent of pelvic and inguinal lymph nodal involvement. Furthermore, it is suggested that the dissection is first made on the side ipsilateral to the penile lesion so that an intraoperative frozen-section pathologic evaluation of all lymphatic tissue specimens can be performed. Dissection of the contralateral side would be deemed unnecessary in the event of ipsilateral lymph node positivity.

Surgical anatomy

The parietal peritoneum covers the structures of the pelvis and forms ligaments and folds that are recognized during laparoscopy [81]. The median umbilical ligament is in the midline and extends from the dome of the bladder to the umbilicus. It contains the obliterated remnant of the urachus. Occasionally this may be patent or form cysts. The medial umbilical ligaments are formed by the obliterated umbilical arteries that originate from the internal iliac arteries. The lateral umbilical ligaments overlie the inferior epigastric vessels.

The gonadal vessels from the lateral aspect and the vas deferens or the round ligament (in females) from the medial aspect converge at the internal inguinal ring. The femoral canal may be visible medial to the external iliac vein. The iliac vessels are exposed upon incision of the peritoneum proximal to where the vas deferens or round ligament encounters the medial umbilical ligament. The common iliac arteries bifurcate into the external and internal iliac arteries about the level of the sacroiliac joint. The external iliac artery exits through the femoral canal to form the femoral artery. The internal iliac artery (hypogastric artery) supplies the pelvic viscera through branches: superior vesical artery, inferior vesical artery, middle rectal, uterine and vaginal arteries in the female, and obturator arteries. The external iliac vein runs medial and posterior to the external iliac artery.

The ureter crosses the iliac vessels in the region of the bifurcation of the iliac artrery. The ureter proceeds medially to the trigone of the bladder posterior to the vas deferens. In the female, the ureter forms the posterior boundary of a shallow depression, named the ovarian fossa, in which the ovary is situated. The vas deferens runs medially from the internal inguinal ring, crossing the external iliac vessels. In the female the round ligament is a homologous structure that runs from the internal ring to the uterus.

The obturator nerve emerges from the medial border of the psoas muscle at the brim of the pelvis, runs along the lateral wall of the pelvis, above the obturator vessels, to the upper part of the obturator foramen, where it enters the thigh. It runs posterior to the iliac vessels close to the bifurcation. The obturator nerve distributes muscular branches to the adductor muscles. The genitofemoral nerve runs on the psoas major muscle in the retroperitoneum medial to the gonadal vessels. It divides into the genital and femoral braches. The genital branch descends on the external iliac artery and passes through the internal ring along the back of the spermatic cord to supply the cremasteric muscle in the male. The femoral branch passes along the inner margin of the psoas muscle beneath the inguinal ligament and is distributed to the upper and anterior aspect of the thigh (Figure 77.3).

The pelvic lymph nodes and lymphatics parallel the vessels after which they are named. The obturator nodes lie along the pelvic side wall adjacent to the obturator nerve. The external and internal iliac nodes drain into the common iliac nodes, which communicate with the presacral nodes and drain into the paraortic nodes. There is also some secondary convergence of the pelvic nodes to the deep inguinal nodes and the femoral nodes.

The anatomic basis for the LPLND follows the lymphatic drainage of the prostate:

- Primary echelon: obturator, hypogastric, external iliac;
- Secondary echelon: presciatic, presacral, distal common iliac;
- Tertiary echelon: proximal common iliac, aortic.

Informed consent

Potential major complications to be discussed include vascular injury causing severe hemorrhage necessitating emergency transfusion or open exploration, and visceral injury including bowel, bladder, and ureteral injury that may require open repair. The potential dangers of CO_2 insufflation should also be discussed: hypercapnia resulting in cardiopulmonary embarass-

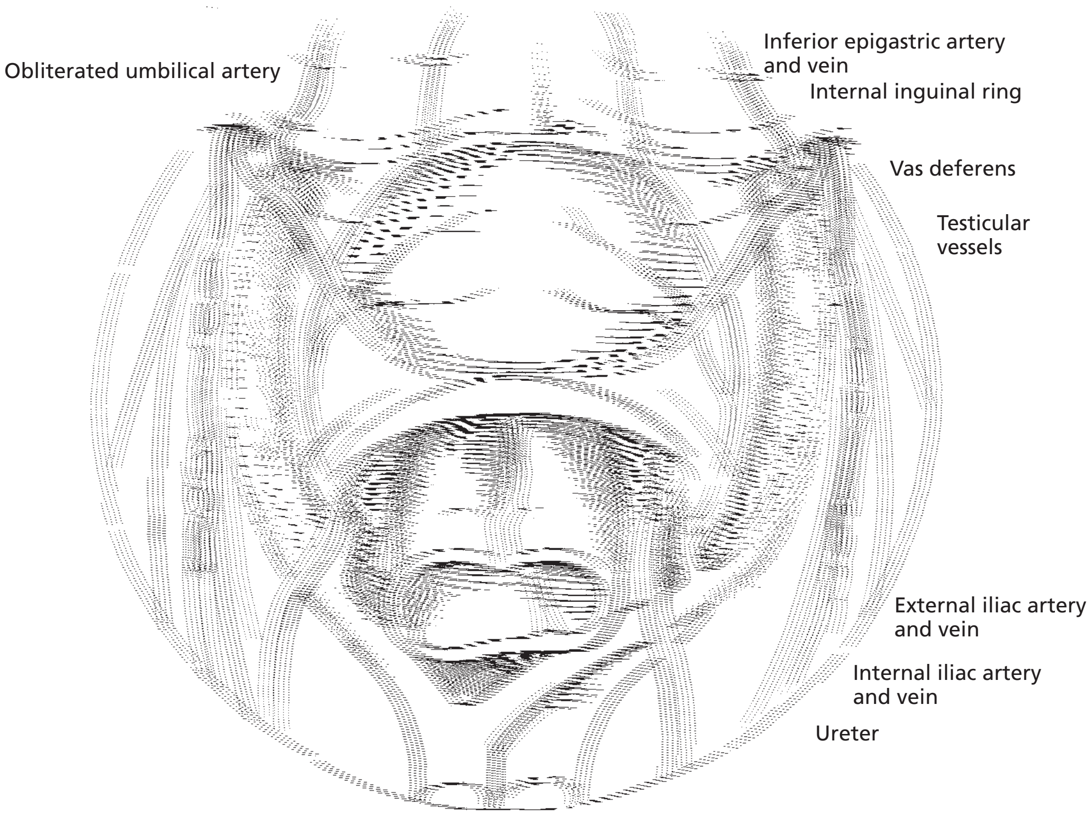
Obliterated umbilical artery
Inferior epigastric artery and vein
Internal inguinal ring
Vas deferens
Testicular vessels
External iliac artery and vein
Internal iliac artery and vein
Ureter

Figure 77.3 Pelvic peritoneum with the underlying structures (reproduced with permission from Brooks, JD. Anatomy of the Lower Urinary Tract and Male Genitalia. In *Campbell's Urology*, 7th ed., W.B. Saunders Company; 1997, p 98.).

ment, painful subcutaneous CO_2 emphysema, pneumothorax, and intravascular CO_2 insufflation. Unsatisfactory dissection may result in poor lymphatic tissue yield. This may be more common during a surgeon's early experience with the surgery. The inability to obtain adequate exposure of the obturator–iliac regions secondary to anatomic confounders, such as obesity, large-scale adhesions, or anomalous vascular architecture, would also oblige the surgeon to convert the procedure to open surgery.

Potential postoperative complications, including lymphedema and lymphocele formation that may require percutaneous drainage, should be understood by the patient. The possibility of hematoma formation, which, if infected, may require open evacuation and drainage, should also be discussed. As with all surgical operations requiring general anesthesia, the attendant risks of pneumonia, myocardial infarction, stroke, and death should be discussed. Other less common complications encountered following LPLND include wound infection or dehiscence, lower extremity deep vein thrombosis, and obturator nerve palsy.

In addition, alternative treatment plans that would negate the need for a lymph node dissection (e.g. watchful waiting for prostate cancer) should be discussed. Furthermore, the experience and operative outcomes obtained by the surgical team should be clarified.

Preoperative preparation

Prior to LPLND, the standard presurgical evaluations are appropriate. These include a general screen of the blood chemistry as well as a hemogram, coagulation studies, a recent chest X-ray, and an electrocardiogram. A blood typing and antibody screen are mandatory since LPLND is not without significant risk of vascular injury and voluminous hemorrhage requiring emergency transfusion. If further radical surgery is planned pending a lymph node biopsy that is negative for metastatic disease, many surgeons advise the patient to bank autologous blood in the event that transfusion becomes necessary during the procedure.

The LPLND candidate is given specific instructions regarding the appropriate preoperative routine. The healthy patient scheduled to undergo LPLND alone who has no previous abdominopelvic pathology, surgery, or radiotherapy is instructed to self-administer either an oral laxative such as magnesium citrate or an enema on the evening before surgery. Decompressing the bowel in this manner decreases the risk of enterotomy. In addition, the patient should be instructed to cease oral intake past midnight and to report for admission to the hospital early on the morning of surgery. In certain clinical situations a more intensive mechanical and antibiotic bowel preparation should be administered the evening before

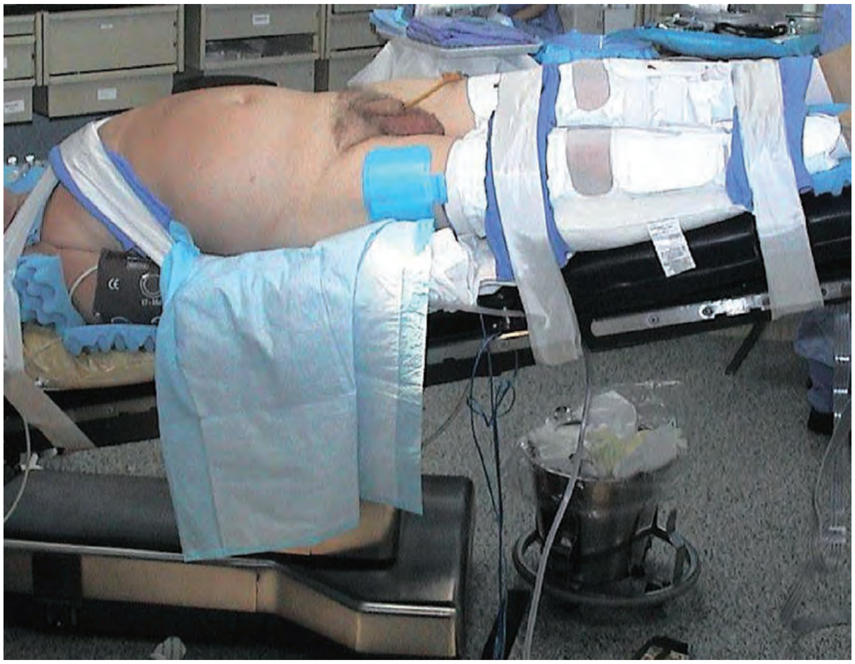

Figure 77.4 Patient is secured to the table in a supine position. The steep Trendelenberg position is needed.

surgery, e.g. if more extensive surgery such as radical cystectomy with urinary diversion is planned in the event the nodes are negative on frozen section examination.

All patients are administered one dose of a broad-spectrum parenteral antibiotic (e.g. 1 g cefazolin intravenously) 1 h preoperatively. On arrival in the operating room, antiembolic pneumatically cycled compression boots are placed on the patient. For improved positioning, muscle relaxation, exposure, and analgesia, general anesthesia is considered most appropriate for LPLND.

The patient is placed in a supine position on the operating table (Figure 77.4). After adequate general anesthesia is obtained, a urethral catheter and an oro/nasogastric tube are inserted.

Both the patient's arms are carefully padded and secured at their sides. Wide adhesive tape may be placed across the chest and thigh to secure the patient to the operating table. Some argue that stress to the shoulders and brachial plexus during Trendelenburg positioning may be caused by the securing of tape to this region. In the case of robotic PLND (RPLND), the patient's legs are spread apart either with Yellowfins or a specialized robotic table, which help in securing the legs. When using the Yellowfins, the legs may be lowered when the table is placed in the Trendelenburg position. Along with the padding that is fixed to the table, this holds the patient sufficiently, avoiding the use of tape in the shoulder region. The entire abdomen, including the groin and external genitals, is then antiseptically prepared and draped in a manner suitable for standard laparotomy. Access to the genitalia during surgery may be helpful in an occasional patient, especially those who are obese, since tugging on the testis can help identify the internal inguinal ring.

Instrumentation and port placement

The 10-mm, 0° or 30° laparoscope is used. The video monitoring equipment should be placed in such a manner as to allow a comfortable and unobstructed view by all members of the surgical team. Ideally, dual monitors should be used on each side of the patient, off the foot end of the operating table.

Laparoscopic lymphadenectomy

For laparoscopic PLND, four to five ports can be used (Figure 77.5). Access is achieved at the umbilicus, where a 12-mm port is placed for the laparoscope. A 5-mm port is placed on either side, approximately 8 cm lateral to the umbilical port and 2 cm inferior. If a very proximal dissection is expected, these trocars can be translated a few centimeters cephalad. In a diamond configuration, the fourth port, a 12-mm port, is placed midway between the umbilicus and the pubic symphysis in the midline (Figure 77.5A). An additional 5-mm trocar can be placed superolaterally to the right-sided trocar for additional retraction in the obese patient (Figure 77.5B). The additional trocar is also typically necessary if a laparoscopic prostatectomy or cystectomy is planned.

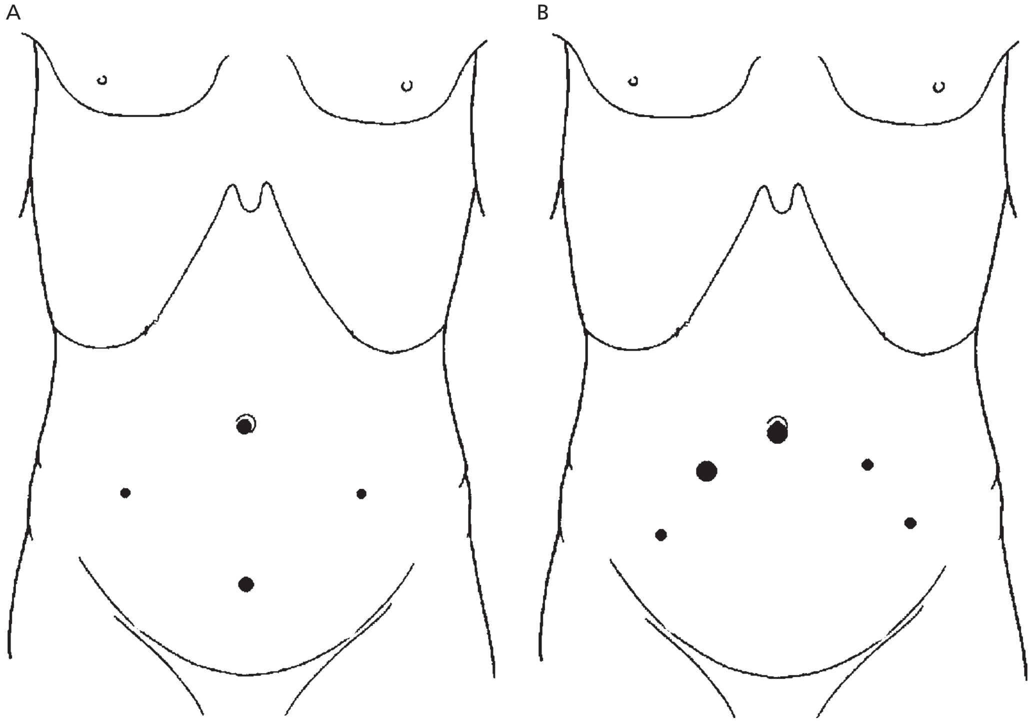

Figure 77.5 Port placement for laparoscopic pelvic lymphadectomy. (A) Diamond configuration and (B) fan configuration: more versatile if planning prostatectomy/cystectomy, and is helpful in obese patients.

Instruments that we use extensively include the Harmonic scalpel® with the curved shears (Ethicon Endo-surgery, Cincinnati, OH, USA), laparoscopic dissectors, and the suction irrigator. Bipolar forceps are invaluable to assist with hemostasis. A 5-mm three-prong or fan-shaped retractor aids in holding loops of bowel cephalad. Five- or 10-mm laparoscopic vein retractors or "mini-curved" retractors are helpful in retracting the iliac vessels laterally to facilitate improved access to the pelvic side wall and obturator fossa. Additionally, 10-mm spoon-shaped laparoscopic forceps can be used to remove smaller portions of the lymph node packet. The 10-mm specimen bag (EndoPouch®, Ethicon Endo-surgery) is used when the specimen is large or the lymph node capsule violated, and with extended LPLND.

As a precaution, particularly during the surgeon's early experience, the surgical nursing staff should have a standard laparotomy tray set-up in the operating room should the need for emergency laparotomy arise. As experience with laparoscopic surgical technique is gained, the need to convert to an open procedure will decrease; however, the open set should always be in the room ready to be used if required.

Robotic lymphadenectomy

In robotic lymphadenectomy, the patient-side cart is usually brought between the patient's legs such that the instrument trays are angled toward the pelvis. The assistant may stand on either the patient's right or left side. Similar to the laparoscopic lymphadenectomy, access is obtained at the level of the umbilicus, or slightly above the umbilicus if a very proximal dissection is expected. A 12-mm port is placed at this location, which is used as the camera port. An 8-mm robotic trocar is placed on either side of this port, approximately 7–8 cm lateral to the camera port and 2 cm inferior (Figure 77.6). These trocars can be moved superiorly if a proximal dissection is expected. An additional robotic trocar can be placed for use as an optional fourth arm, approximately 8 cm lateral to either the right or left robotic trocar. On the opposite side, but in a similar location, a 12-mm port is placed for the assistant. An additional 5-mm port can be placed 3 cm superior to the midpoint between the umbilical and right or left robotic port, on the same side as the other assistant port.

The monopolar scissors and PK dissecting forceps are typically used as the primary dissecting instruments. The Prograsp is also useful for additional retraction by the fourth robotic arm. The assistant typically uses a suction irrigator. Additionally, a prostate grasper or atraumatic grasper can be used by the assitant for additional traction. A laparoscopic spoon can be used by the assistant to remove smaller specimens. Laparoscopic clips, 5- and 10-mm Hem-o-lok® polymer locking clips (Weck Closure System, Research Triangle Park, NC, USA) may also be necessary.

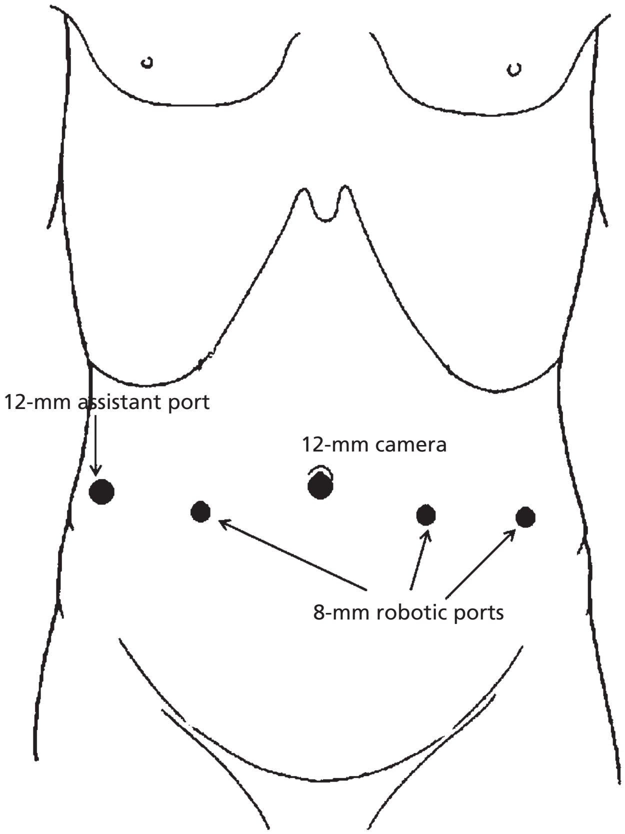

Figure 77.6 Robotic port placement. For more proximal dissection, the ports can be shifted superiorly.

Technique

Transperitoneal pelvic lymph node dissection

After adequate pneumoperitoneum has been obtained and the placement of a 10/12-mm subumbilical port has been accomplished, a 0° (or 30°) telescope is then introduced into the abdominal cavity and a thorough and systematic survey of the abdominal contents is performed to rule out injury or gross metastatic disease. Any extensive adhesions or fatty tissue deposits in the vicinity of the umbilical ligaments are noted since these findings may indicate the need for a modification of the standard diamond configuration of working port placement. Adhesions near the sites selected for working port positions may require lysis before port placement can be completed. Ports are then placed under vision in the configuration described previously.

At this point adhesions interfering with proper exposure of the obturator fossa may require lysis. This is particularly true of dissection on the left side since sigmoid colonic diverticular inflammation may create adhesions of the sigmoid colon to the pelvic side wall. Incising along the white line of Toldt should easily mobilize the sigmoid colon to allow a clear view of the obturator–iliac region. Additional reflection of the bowel cephalad allows exposure of the more proximal vessels.

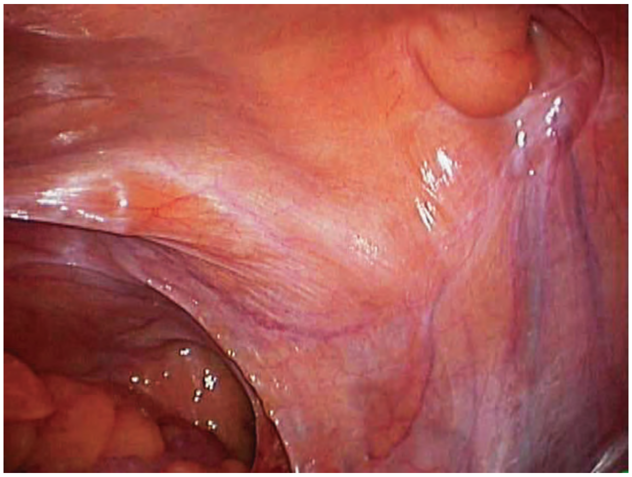

Figure 77.7 Laparoscopic view of the right hemipelvis.

It is necessary to accurately identify several important landmarks before beginning dissection of the pelvic lymph nodes (Figures 77.3 and 77.7). The testicular vessels and vas deferens should be identified as they enter the pelvis via the deep inguinal ring. The testicular vessels continue cephalad, while the vas deferens runs posteromedially over the iliac vessels and the obliterated umbilical artery (ligament) en route to its position alongside the seminal vesicles deep within the pelvis. The umbilical ligament should be seen extending from the anterior abdominal wall on its way to join the internal iliac artery near the bifurcation of the common iliac artery. It should be noted that the "obliterated" umbilical artery is often widely patent near its junction with the internal iliac artery, and has been the source of significant hemorrhage following accidental transection. In nonobese patients, pulsation of the external iliac artery may indicate its position beneath the peritoneum.

Obturator pelvic lymph node dissection

Obturator lymphadenectomy has been thought to be an appropriate procedure for the pathologic staging of patients with lower risk prostate cancer. Though recently it has been demonstrated that survival is not affected by lymph node dissection in these patients, there may be some prognostic value in patients with a risk of positive lymph nodes of less than 10%. Dissection should begin on the side that is more likely to harbor nodal metastases. This includes the side of the positive prostate biopsies or prostate nodule. If there is no preference for the side based on preoperative data, dissection of the right side is performed first since adhesions requiring colonic mobolization are more common on the left side. The initial incision through the posterior peritoneal

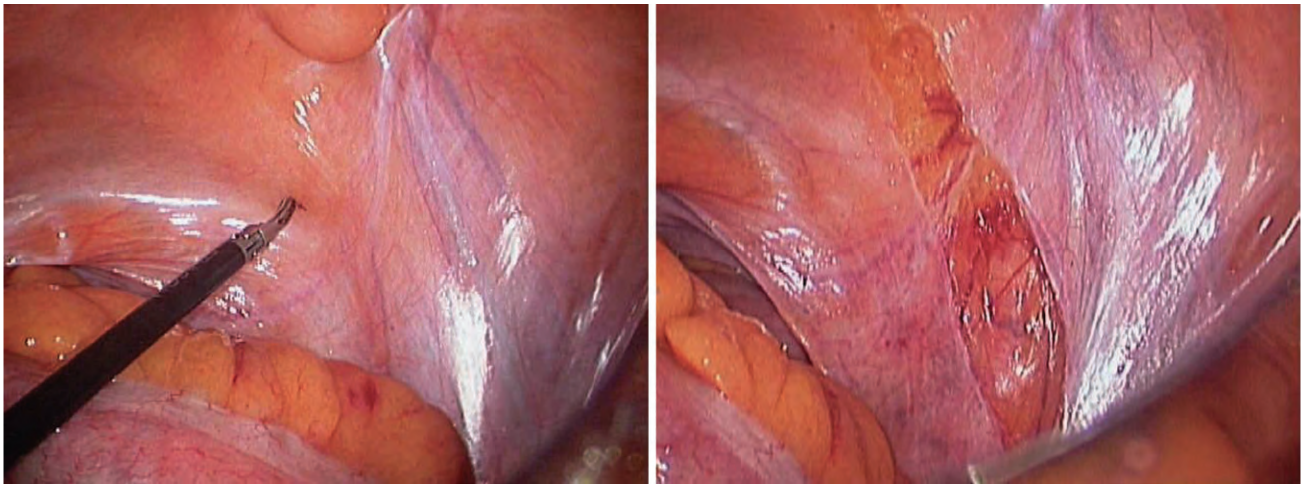

Figure 77.8 Incision is made in the peritoneum just lateral to the obliterated umbilical artery.

membrane begins at a point approximately midway between the obliterated umbilical artery and the internal inguinal ring high over the pubic bone. It is then extended cephalad, medial to the external iliac artery, toward a point near the bifurcation of the common iliac artery (Figure 77.8). The anatomic relationship of the ureter to the bifurcation of the common iliac artery must be well conceptualized by the surgeon to avoid transection requiring stenting or possibly open repair. The vas deferens with its deferential artery is then identified, dissected free, and transected using electrocautery. Alternatively, an incision can be made just lateral to the medial umbilical ligament. The bladder is reflected with blunt and sharp dissection away from the sidewall. The peritoneum is then carefully incised proximal to the vas deferens, along the direction of the external iliac artery. This creates exposure for the whole extent of the dissection. When using the robot, the fourth arm or assistant can help retract the bladder medial to maintain exposure.

The external iliac vein is exposed by careful dissection of all fibrofatty lymph node-bearing tissue medial to the external iliac artery. With the use of blunt and sharp dissection techniques, the lateral border of dissection is formed by clearing all fibrolymphatic tissue from the anterior and medial surfaces of the external iliac vein, as well as the tissue underneath the vein, extending to the side wall.

Gentle medial traction placed on the obliterated umbilical artery forms a plane delineating the medial boundary of the obturator node packet. Blunt dissection lateral to the obliterated umbilical artery is continued inferiorly to develop this plane to the level of the pubic bone and Cooper's ligament (Figure 77.9). This completes the inferior apex of the dissection. In this area venous variations are frequently encountered. Not uncommonly an accessory obturator vein may be identified as it joins the external iliac vein just after the iliac vessels enter the pelvis through the femoral canal. With careful manipulation, the inferior apex of the obturator lymph node packet may be maneuvered beneath this tributary, but as is often the case, clips should be placed on the accessory vein proximally and distally, followed by division, before the distal lymph node packet can be freed. Five- or 10-mm Hem-o-lok® clips are recommended since these locking clips are less prone to dislodge during further dissection in the region. Alternatively, bipolar cautery or PK forceps can sufficiently cauterize these vessels in most cases.

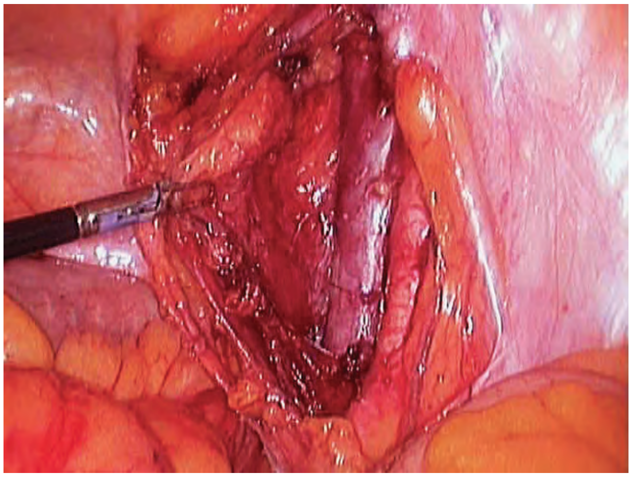

Figure 77.9 Dissection is carried out distally to the pubic bone along the external illac vessels.

The distal extent of the lymph node packet is freed with judicious use of electrocautery or ultrasonic shears. A clip is used at the distal end to occlude lymphatics and minimize the risk of a postoperative lymphocele.

The free distal apex of the node packet is then grasped and elevated using proximally directed traction. With blunt dissection at the base of the node packet, the underlying obturator nerve and vessels should come into view as gentle traction draws the packet superiorly. During dissection of the lymph node packet toward the bifurcation of the common iliac artery, any small blood or lymphatic vessels encountered should be sealed with electrocautery or ultrasonic shears. Normally the obturator vessels are preserved as their course is medial and slightly posterior to the obturator nerve. These vessels may be controlled and divided if required. Again, it must be remembered that as the dissection nears the bifurcation of the common iliac artery, the proximity of the ureter puts it at risk of unintentional injury.

When the level of the common iliac bifurcation is reached, the proximal lymphatic vessels are cauterized, clamped with a Hem-o-lok clip, and divided, resulting in a free lymph node packet (Figure 77.10). With 10-mm spoon-shaped laparoscopic forceps, the free lymph node packet is delivered through a 10/12-mm port using a gentle twisting motion. The flap valve at the entrance to the port must be manually opened during extraction of the lymph node packet to avoid shearing and loss of lymphatic tissue within the barrel of the sheath. Laparoscopic visualization of the intracorporeal open end of the sheath during extraction of the lymph node packet will further ensure that no lymphatic tissue is dislodged from the packet during removal, and facilitate immediate location and recovery of any lymphatic tissue accidentally sheared from the packet during extraction. If the lymphatic tissue is large or there is concern of violation of the lymph node capsule, a 10-mm entrapment sac (EndoPouch®) may be used for specimen retrieval.

If immediate radical surgery is planned pending a negative histopathologic evaluation of the lymphatic tissue specimen, the lymph node packet is sent for immediate frozen section analysis and attention is then turned to the opposite side. If radical surgery is not planned, we rarely order frozen-section histopathologic evaluation of the lymph node specimens. If immediate radical surgery is not planned, we send the nodes from the first side for frozen-section analysis, since a positive node on the first side could obviate dissection on the contralateral side. The false-negative rate of frozen section evaluation of lymph node sampling can be as high as 19% [82]. The table is rotated in the opposite

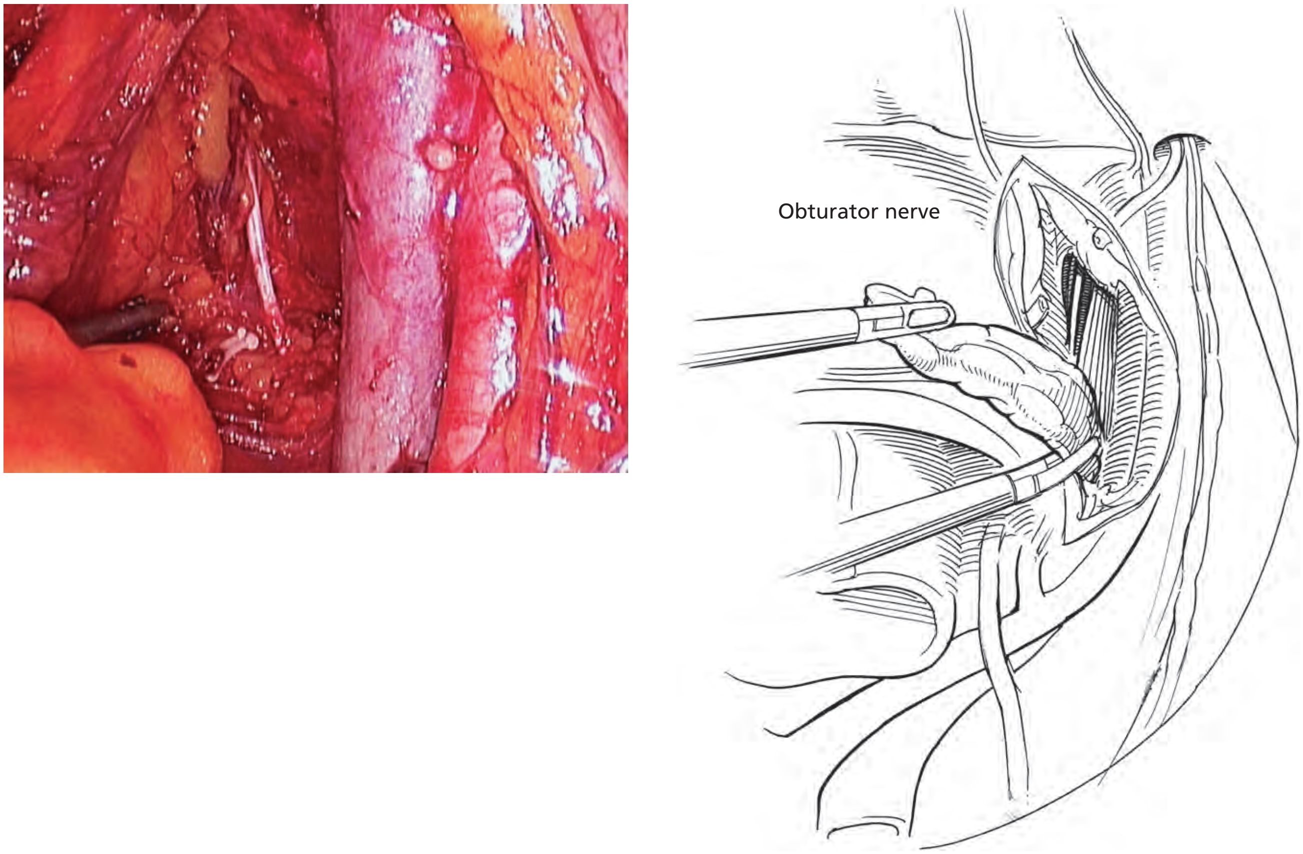

Figure 77.10 Tissue is removed from the medial aspect of the external iliac vessels, pelvic side wall, and the obturator nerve up to the iliac bifurcation.

direction and a similar dissection proceeds on the contralateral side.

At the conclusion of the laparoscopic procedure, a thorough evaluation of the abdomen is necessary. Particular attention is directed to the operative sites to ensure that meticulous hemostasis has been achieved. Intra-abdominal pressure is lowered to approximately 5 mmHg to permit identification of any venous bleeding formerly tamponaded during the higher intra-abdominal pressures maintained throughout the procedure. Since the physical presence of the ports may tamponade any potential bleeding from a lacerated abdominal wall vessel, the secondary ports are all removed under direct laparoscopic visualization. The primary port is removed over the laparoscope, the laparoscope being the last instrument to exit the intra-abdominal space. This guards against herniation of abdominal contents and allows for a final inspection for hemorrhage formerly tamponaded by the camera port. In addition, digital exploration of all 10/12-mm port incisions may be performed to rule out herniation before closure. Any residual CO_2 is expressed out of the abdominal cavity and all puncture sites that are 10 mm or larger are closed separately with a single 2-0 polydioxanone suture on the fascia. The oro/nasogastric tube is removed before the patient emerges from the anesthesia. The patient is then transferred to the postanesthesia care unit for routine postoperative monitoring.

Nuances with robotic lymphadenectomy

With the increased use of robot-assisted surgery for prostate and bladder surgery, pelvic lymphadenectomy is often performed robotically. The manner of dissection is the same for robotic surgery, but a couple of differences warrant description. As mentioned previously, due to the decreased instrument range, careful placement of the ports is necessary. If a proximal dissection is expected, the ports should be placed more cephalad than usual. Camera angle can also improve the range that can be visualized via the robotic camera. Distally, a 0° or 30° upward camera may be helpful, but more proximally, a 30° downward camera is helpful.

A fourth robotic arm can aid in retraction of the bladder medially on the side opposite to which it is placed. For dissection on the same side as the fourth arm, the assistant retracts the bladder medially. The fourth arm can then be used to hold the lymph node packet on traction.

Rotation of the table in laparoscopic lymphadenectomy helps retract the bowel away from the proximal areas of dissection. However, this is not possible in robotic lymphadenectomy. Thus, mobilization of the bowel medially by reflecting it off the posterior peritoneum is important to provide access. Additional retraction with a fan via the assistant port may be necessary.

Extended pelvic lymph node dissection

As previously mentioned, certain clinical indications merit a more extensive lymph node dissection:

- Carcinoma of the urinary bladder, urethra, or penis;
- Carcinoma of the prostate in the absence of gross obturator lymph node positivity in (1) PSA elevation in excess of 20 ng/mL (Hybritech assay); (2) a Gleason score of 8 or greater (as lymph node positivity would be expected in over 40% of cases); and (3) clinical stage C (T3) disease.

In order to gain access to this broader region of dissection, a more extensive mobilization of the sigmoid colon and cecoappendiceal regions are required. Alternatively, an inverted V peritoneotomy has been described that may provide greater exposure of the obturator–iliac region [41]. This includes a second peritoneal incision that originates at the same point over the pubic bone as the initial incision, and continues posteromedially and equidistant to the initial incision. This forms a triangular peritoneal free flap based along the medial umbilical ligament and the spermatic cord, which, when elevated, allows a more thorough exposure of the underlying obturator–iliac region. Full access to the lymphatic tissue deep to these vessels is facilitated by gentle medial retraction of the external iliac artery and vein.

Boundaries of pelvic lymphadenectomy (Table 77.1)

Lateral border

In contrast to limited PLND, the lateral border of extended PLND includes the lymph nodes anterior and lateral to the external iliac vein to the level of the genitofemoral nerve. The incision of the peritoneum is made lateral to the medial umbilical ligmament, and the obturator lymph nodes can be dissected as before. The lymph nodes covering the external artery are then rolled over the artery. The genitofemoral nerve is identified, and the peritoneum and lymphatic tissue is divided just medial to this. This can be extended cephalad to dissect the tissue between the psoas and the lateral aspect of the common iliac artery. Gentle retraction of the artery medially can aid in this dissection.

Proximal limit

The proximal limit of the extended PLND for prostate cancer is the common iliac artery, while for bladder cancer it should include the aortic bifurcation. Some

Table 77.1 Boundaries of pelvic lymphadenectomy.

Boundaries	Limited	Extended – prostate	Extended – bladder
Lateral	External iliac vein	Genitofemoral nerve	Genitofemoral nerve
Medial	Medial umbilical ligament	Ureter, bladder	Presacral nodes
Inferior	Pubis	Pubis	Pubis
Superior	Bifurcation of common iliac artery	Distal common iliac artery	Aortic bifurcation
Posterior	Obturator nerve	Presciatic tissue, hypogastric artery	Presciatic tissue, hypogastric artery

sources include the distal aortic nodes up to the level of the inferior mesenteric artery. In order to reach these lymph nodes, it must be ensured that the ports are placed high enough on the abdomen to reach this location, which may require the camera port to be placed cephalad to the umbilicus. Mobilization of the cecum and sigmoid colon aid in obtaining adequate exposure of this region. The dissection usually starts on the right side, as the exposure and dissection are more difficult on the left due to the presence of the sigmoid colon. Incision of the peritoneum following the direction of the common iliac artery allows safe exposure of this area. It is helpful to divide the lymph node packet overlying the common iliac artery, taking care to avoid the ureter. The lymph node tissue is rolled off the lateral surface of the external iliac artery. The remaining packet is retracted medially to visualize the common iliac vein. Additional dissection proceeds medial to cover the presacral lymph nodes. This is more easily approached from the right, as the sigmoid can be retracted laterally to provide exposure. Excessive deep dissection in this area should be avoided to prevent bleeding. The aortic nodes can be dissected with this exposure also. The left-sided dissection is performed in a similar manner.

Posterior dissection

The lymph node tissue that lies underneath the obturator nerve represents a significant drainage region for both prostate and bladder cancer. It encompasses the lymph nodes along the medial surface of the internal iliac artery. These lymph nodes can be accessed after the dissection of the obturator lymph nodes. The obturator lymph nodes, when freed, except at the base, can be passed underneath the obturator and retracted medially to provide exposure. Alternatively, the obturator nodes can be removed as a separate packet. Vessel and lymphatic branches are found laterally and posteriorly and should be clipped as the packet is retracted medially (Figure 77.11).

Extraperitoneal pelvic lymph node dissection

It is evident that by maintaining the integrity of the peritoneal membrane, the risks of visceral injury, intraperitoneal spillage of potentially tumor-laden lymphatic tissue, and postoperative development of intra-abdominal adhesions associated with direct instrumentation and manipulation of the intraperitoneal contents may be decreased or avoided. Additionally, tedious and time-consuming adhesiolysis, followed by mobilization of sigmoid colonic and cecoappendiceal regions that often must precede exposure of the obturator–iliac regions, is avoided with the extraperitoneal approach. Furthermore, the intact peritoneum may help ameliorate the difficulty of obtaining adequate exposure commonly encountered in the obese patient. By retaining the fat-laden loops of bowel and omentum (that tend to fall into the operative field) within the peritoneal cavity, the intact peritoneum passively facilitates exposure of the obturator–iliac region. This in turn may lessen the need for the extreme Trendelenburg position typically used to gravitate these barriers away from the operative site.

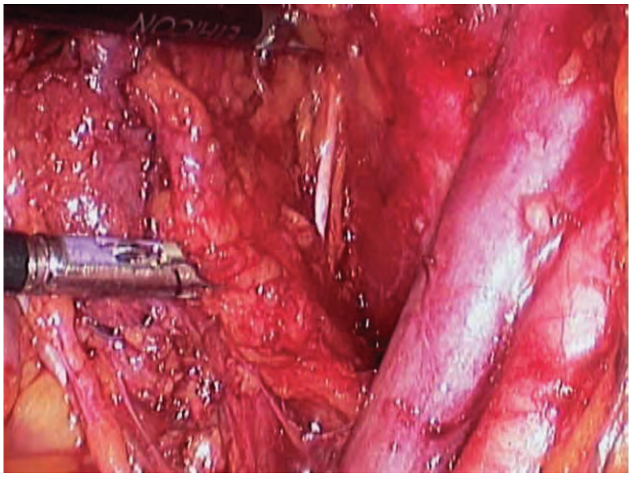

Figure 77.11 Nodal tissue is removed beneath the obturator 1nerve, medial to the internal iliac vessels. Tissue medial to this can also be removed.

On the contrary, several disadvantages of this alternative approach have been noted. The working space available for extraperitoneal LPLND is limited by the ability to successfully develop and insufflate the properitoneal space. Even with excellent expansion and CO_2 insufflation, the properitoneal working area is much more confined than in the intraperitoneal space. Also, the balloon dissection required to develop the properitoneal space produces a shearing effect between the parietal surface of the peritoneal membrane and the overlying fascial layer. This results in a tattered appearance of the properitoneal space. This effect, combined with the cephalad displacement of the vas deferens, may present a confusing picture to the laparoscopic surgeon. The lymph nodes along the internal iliac artery, as well as more proximally placed lymph nodes, are difficult to reach with this technique [83].

In a patient with a history of lower abdominal or pelvic intra- or extra-peritoneal surgery, the resultant postoperative sequelae of fibrosis and scarring within the tissue planes of the abdominal wall may severely limit expansion of the properitoneal space. Similarly, the fibrosis and scarring following extraperitoneal LPLND may complicate future regional procedures such as radical retropubic prostatectomy. In addition, the potentially higher likelihood of lymphocele formation and extensive subcutaneous CO_2 emphysema may complicate the extraperitoneal LPLND candidate's postoperative course.

Creation of the extraperitoneal space

The patient is placed supine under general anesthesia with endotracheal intubation. About 2 cm below the umbilicus, a 3-cm vertical midline incision is carried inferiorly and deepened to the level of the rectus abdominis fascia. The properitoneal space is then entered by splitting the rectus abdominis and transversalis fascia. The latter fascial layer is deep to the rectus abdominis muscle below the umbilicus and arcuate line. A properitoneal space is developed using blunt finger dissection to the extent that a balloon dilation device can be introduced.

A modification of the device described by Gaur *et al*. for creation of the retroperitoneal working space while attempting the first extraperitoneal laparoscopic nephrectomy has proved successful in expanding the properitoneal space [84]. This device features the finger cot of a transurethral resection drape secured to a 20F red rubber (Robinson) catheter by silk-free ties. The thicker polyethylene natural rubber material has demonstrated the ability to withstand pressure exerted by injection of the 800–1000 mL of saline solution required to adequately expand the properitoneal space. This is important since balloon rupture during expansion will mandate a thorough search of the properitoneal space for fragments. Fortunately, if the polyethylene balloon ruptures, the fragments tend to be large and easily recoverable. Latex fractures into smaller pieces, which may lead to a serious inflammatory or allergic response if retained. A commercially available preperitoneal balloon may be used to create the extraperitoneal working space.

With successful dilation of the space of Retzius, the pubic bone and external iliac vessels become visible. We use a self-retaining, 10-mm Bluntport trocar which has a inflatable balloon and a foamgrip anchoring device (US Surgical, Norwalk, CT, USA). Twelve to 15 mmHg of CO_2 is insufflated through the cannula. In the standard diamond configuration the working ports are then placed carefully into the properitoneal space so as to avoid traversing the peritoneal membrane. The working ports are placed under direct laparoscopic guidance. Should the peritoneal membrane be violated, the properitoneal space will likely be obliterated. This situation will necessitate conversion of the port placement from the extra- to an intra-peritoneal position.

Afferent lymphatics are controlled with clips or bipolar cautery to minimize the possibility of a postoperative lymphocele. With the exception of creating a peritoneotomy, extraperitoneal LPLND proceeds in the same sequence as described for the intraperitoneal approach to obturator lymph node dissection once the ports are in place.

Postoperative care

All patients are admitted to hospital following laparoscopic surgery. They receive two additional postoperative doses of a parenteral broad-spectrum antibiotic at an 8-h interval and their diet is advanced as tolerated. Ambulation should be tolerated on the evening of surgery, and any postoperative pain should be manageable with oral analgesics; parenteral narcotics are rarely indicated. Most patients are discharged from hospital within 24 h of surgery and should be able to resume normal activity within 1 week.

Results

The results of several series of patients who underwent LPLND are summarized in Table 77.2. The transperitoneal approach is most widely used. Compared to the extraperitoneal approach, there is more operating space and the anatomic landmarks are easier to identify with the transperitoneal approach. LPLND retrieves a number of nodes that is similar to that with the open approach, in experienced hands. Compared to open surgery there is a shorter convalescence and hospital stay [85, 86].

There are few reported series of patients who undergo the extraperitoneal approach. In a series of 36 patients from Das in 1996, the operative time was between 50 and 110 min, with a blood loss of 30–65 mL [86]. In three patients the procedure was not possible via the laparoscopic approach. The mean number of nodes harvested was 12.2, and in 16.6% of patients metastatic prostate cancer was detected on frozen-section analysis.

Table 77.2 Results of transperitoneal laparoscopic pelvic lymph node dissection (LPLND) in the English literature.

Study/review	Number of patients	Cancer	Number of nodes	Mean operative time (min)	Mean hospital stay (days)	Number of complications (%)	Number of conversions (%)
Winfield *et al.* 1992 [109]	66 laparoscopic	Prostate	9.6	150	1.5	17 (26) No lymphoceles	11 (16)
Schuessler *et al.* 1993 [96]	147 laparoscopic	Prostate	45.8	158	2	46 (31)	4 (3)
Kerbl *et al.* 1993 [85]	30 laparoscopic (L) 16 open (O)		–	L: 199 O: 102	L: 1.7 O: 5.3	L: 6(20) O: 0	0
Rukstalis *et al.* 1994 [92]	103 laparoscopic	Prostate, bladder, penile	8.9	156	1.6	14 (14)	10 (10)
Doublet *et al.* 1994 [110]	29	Prostate	8.4	90	2	6 (21)	3 (10)
Lang *et al.* 1994 [97]	100 laparoscopic	96 prostate 2 bladder, 2 penile	9.3	138	1.1	9 (9)	0
Klän *et al.* 1995 [111]	70	Prostate	13.6	136	–	11 (16)	2 (3)
Brant *et al.* 1996 [89]	60 laparoscopic (L) 51 mini-laparotomy (M)	Prostate	L: 10 M: 16	L: 120 M: 35	L: 1 M: 0	L: 2 (3) M: 0	2 (3)
Stone *et al.* 1999 [112]	189	Prostate	9	75	1°	17 (9)	0
Parkin *et al.* 2002* [113]	50	Prostate	–	110	1.8	9 (22)	1 (2)
Lattouf *et al.* 2007 [8]	35 laparoscopic extended PLND	Prostate	14	90		5 (15)	0
Abraham *et al.* 2007 [114]	14 robotic (R) 20 laparoscopic (L)	Bladder	R: 22 L: 16	R: 410 L: 419	R: 6 L: 6	R: 4 (28) L: 14 (70)	R: 0 L: 3 (15)
Murphy *et al.* 2008 [115]	23 robotic	Bladder	16	234 robotic time	11.6	6 (26)	0
Guru *et al.* 2008 [116]	67 robotic	Bladder	18	44	–	1 (1.5)	0
Yee *et al.* 2009 [47]	32 robotic extended PLND	Prostate	18	72	2	1 (3)	0
Cooperberg *et al.* 2009 [91]	141 robotic (R) 337 open (O)	Prostate	R: 9.3 O: 14.4	–	–	R: 2 (1.4) O: 2 (0.5)	–
Touijer *et al.* 2009 [32]	603 laparoscopic	Prostate	12	–	–	–	–
Pruthi *et al.* 2010 [117]	100 robotic	Bladder	19	276 total	5	8 (8)	0
Eden *et al.* 2010 [6]	374 LRP 253 standard (S) 121 extended (E)	Prostate	S: 6.1 E: 17.5	S: 180 E: 207	S: 3 E: 3	S: 9 (3.6) E: 10 (8.3)	0

*Both transperitoneal and extraperitoneal approaches were used.
LRP, laparoscopic radical prostatectomy.

Postoperative complications included a hematoma in one patient and a lymphocele in another [86].

The theoretical benefits include less risk of bowel injury, decreased incidence of postoperative ileus, and a shorter operative time. Twenty-two patients were randomized to transperitoneal or extraperitoneal approaches. The duration of surgery was less with the extraperitoneal group (87 vs 117 min). However, four patients in the extraperitoneal group were converted to the open approach due to epigastric artery bleeding and problems with gas leakage. Lymphoceles developed in two patients in the extraperitoneal group [87].

In a comparative study between similar groups of 12 and six patients who underwent transperitoneal LPLND and extraperitoneal LPLND, respectively, it was determined that the absorption of CO_2 was significantly greater and more rapid during extraperitoneal LPLND. However, in all but one patient hypercarbia and acidemia were prevented by an increased ventilatory rate. The extraperitoneal approach may not be the preferred option in patients with cardiopulmonary disease [88]. The operative time should be minimized and subcutaneous emphysema avoided to decrease the incidence of hypercarbia.

The effectiveness of LPLND has been documented with similar nodal yields when compared to open PLND [89–91]. Rukstalis *et al.* performed open surgery immediately following LPLND to determine the completeness of the laparoscopic approach. They found that 87–95% of the nodes could be removed laparoscopically [92]. The effect of inadequate nodal excision during the learning curve was demonstrated by Guazzoni *et al.* in 1994 [93]. Open surgical revision of the lymphatic tissue during radical retropubic prostatectomy in 30 patients who underwent LPLND, revealed a mean of over six residual lymph nodes in each patient. The number of residual nodes progressively decreased, especially after the first 20 patients.

Complications

Complication rates reported for LPLND and RPLND range from 3.7% to 33%, with most complications being minor [68, 94–96]. The complication rate decreased markedly with the surgeon's experience with the operation. In a study by Lang *et al.* the complication rate was 14% in the first 15 cases and only 4% in the next 50 cases [97]. In recent years, increasing numbers of residents are being trained in advanced urologic laparoscopy during their residencies. Furthermore, many more advanced laparoscopic procedures like nephrectomies and prostatectomies are being performed. The learning curve for this operation is likely to be much less.

The complications reported following LPLND are listed in Table 77.3 [98]. Lymphoceles are infrequently reported following LPLND. However, subclinical lymphoceles were detected in 30.4% (seven) of patients who underwent pelvic CTs following LPLND prior to undergoing radiotherapy [91]. Only 3.5% (two) of patients developed symptomatic lymphoceles. One of these patients required percutaneous drainage with sclerotherapy; the lymphocele resolved spontaneously in the other patient [99]. Symptomatic lymphoceles are more frequently seen following extraperitoneal LPLND, since the peritoneal drainage of the lymphatic fluid is not available. Prophylaxis against deep vein thrombosis requires the use of an intermittent pneumatic compression device during and after surgery. Subcutaneous heparin or enoxaparin (Lovenox®) can also be given, and is becoming standard at many institutions. Though there has been previous concern about increased blood loss or lymphoceles with such pharmacologic prophylaxis, there is evidence to suggest that there is no, or at most a very small, difference in blood loss or lymphoceles with prophylaxis. In a prospective series of 579 patients, the use of subcutanseous heparin did not influence the rate of blood loss or lymphoceles [100]. Koch *et al.* found a slight increase in the incidence of postoperative wound hematomas and lymphoceles

Table 77.3 Complications of transperitoneal laparoscopic pelvic lymph node dissection (adapted from Gill and Clayman [98], with permission).

Total number of patients (multiple centers)	442
Total number of complications	59 (13%)
Intraoperative complications (n = 19):	
Anesthetic complications	1
Unable to access peritoneum	1
Organ injuries:	
Vascular	9
Bladder	3
Ureter	2
Obturator nerve	2
Bowel	1
Postoperative complications(n = 40):	
Urinary retention	7
Lymphocele/lymphedema	5
Prolonged ileus	5
Deep vein thrombosis	5
Prolonged scrotal edema	3
Bleeding requiring transfusion	3
Significant ecchymosis	2
Wound infection	2
Delayed diagnosis of bowel injury	2
Small bowel obstruction	2
Anesthetic complications	1
Fascial dehiscence	1
Pelvic hematoma	1
Retroperitoneal abscess	1
Secondary open surgical intervention	13
Complete lymphadenectomy could not be done	17

with the use of low molecular weight heparin in 160 patients undergoing open prostatectomy, but concluded that its use was generally safe [101]. The incidence of scrotal and penile edema and leg edema was 28% and 10%, respectively, in patients undergoing extended pelvic lymphadenectomy [102].

Vascular injuries specific to PLND can occur during dissection of the nodal tissue in the vicinity of the external iliac vein and aberrant obturator vessels. The external iliac vein may be compressed by the intra-abdominal pressure and therefore may not be readily apparent. The intra-abdominal pressure can be reduced to 10 or 5 mmHg for better visualization of the vein. The pulsation of the external iliac artery is a landmark that can help with localization of the vein that lies medial to the artery. Should vascular injury occur, increasing the intra-abdominal pressure to 20 mmHg and direct compression on the bleeding surface should be the initial maneuver. Hemostatic adjuncts, such as gelatin matrix (e.g. Floseal®; Baxter, Deerfield, IL, USA) and oxidized methylcellulose (e.g. Surgicel®; Johnson & Johnson, New Brunswick, NJ, USA) when combined with compression are most helpful in this situation. In rare situations, proximal and distal control is obtained and suturing is performed. However, the vessels, especially veins, are friable in this region, making it possible to worsen the vascular injury by suturing. Thus, laparoscopic suturing of these injuries should only be attempted if the surgeon is experienced with intracorporeal suturing. Bipolar coagulation should also be avoided if the injury is directly on the larger vessels as this will usually worsen the injury. If bleeding continues, other measures, including conversion to open surgery or endovascular stenting, may be required.

Injury to the bladder may occur during extended LPNLD where the medial boundary can extend to the bladder. The bladder can be repaired in two layers with intracorporeal suturing using 2/0 polyglactin suture. Ureteral injury should be avoided at the bifurcation of the external iliac artery, by identification of the ureter. During more caudal dissection the ureter should not be encountered if the dissection remains lateral to the medial umbilical ligament. Ureteral injury can be repaired laparoscopically if the injury is immediately identified and if the distal segment is healthy and viable. If there is any doubt of the viability of the distal ureter, ureteral reimplantation is recommended by either a laparoscopic or open approach, in which a refluxing, extravesical anastomosis is adequate

Port site metastases

Port site metastases have been reported to our knowledge in three cases of LPLND for urologic malignancies: one for prostate cancer and two for bladder cancer [103–105]. An entrapment sac was not used in all these cases. Both the bladder TCCs were T3 lesions. It is therefore advisable that when LPLND is being performed for TCC or advanced high-grade prostate cancer, an entrapment sac be used to minimize contamination of the port site during specimen retrieval. The risk of port-site metastases is however exceedingly small. When the risk for recurrence is high, other precautions that have been recommended include avoidance of nodal capsular rupture, trocar fixation to prevent dislodgment, avoiding gas leakage along and around the trocar, placing drainage when needed before desufflation, povidone–iodine irrigation of instruments, trocars, and port-site wounds, and suturing 10-mm and larger trocar wounds [106].

Mini-laparotomy

Surgeons without laparoscopic skills can perform the PLND via a small midline 6-cm incision. Bilateral inguinal incisions with aggressive retraction have also been successful. Perrotti *et al.* compared the mini-laparotomy with LPLND and standard open surgery and found that nodal yield with mini-laparotomy was similar to standard surgery and morbidity, and hospital stay was similar to LPLND. The operative time was 90 min with the mini-laparotomy compared to 190 min for LPLND [107]. Herrell *et al.* in a similar study noted no difference in number of nodes obtained by either of these approaches. Multiple complications occurred in the standard open group with no complications in the other two groups [108].

Conclusions

LPLND dissection for prostate cancer is being performed in selected patients, since most patients with prostate cancer in developed countries have early, localized malignancy. However, recent data suggest a benefit in performing an extended lymphadenectomy for those patients with high-risk prostate cancer and for any bladder, urethral or penile cancer. A meticulous dissection that duplicates open surgery is required when this operation is performed. Lymph node dissection as part of laparoscopic radical prostatectomy and laparoscopic cystectomy will be performed in increasing numbers in the next decade.

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CHAPTER 78

Endoscopic Subcutaneous Modified Inguinal Lymph Node Dissection for Squamous Cell Carcinoma of the Penis

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Introduction

The extent of metastatic disease to the lymph nodes is the most important prognostic indicator of survival in patients with squamous cell carcinoma of the penis. Almost 50% of penile cancer patients will harbor metastatic nodal disease. Lymphadenectomy is frequently required for adequate cancer staging and can also be curative when cancer is isolated to the penis and regional nodes [1, 2]. However, inguinal lymph node dissection is not without potential morbidity. Serious, life-altering complications have been associated with inguinal lymph node dissection, including infection, flap necrosis, vascular erosion, and lower extremity lymph edema, and for this reason controversy still surrounds the utility of bilateral and prophylactic dissection.

In 2002, Ian M. Thompson conceived the idea of applying laparoscopic techniques in an endoscopic, subcutaneous approach, with the hope of decreasing the morbidity associated with open surgery by preserving the continuity of the lymphatic and vascular supply to the overlying skin. Working together, we combined different techniques from traditional laparoscopy, subcutaneous endoscopic brow lift, and subcutaneous saphenous vein harvest to formulate an approach using laparoscopic instruments for inguinal node dissection in staging penile cancer. The result is the endoscopic subcutaneous modified inguinal lymphadenectomy (ESMIL) procedure, which mimics the same oncologic approach, anatomic boundaries, and extent of dissection traditionally performed through an open incision.

We first explored the feasibility of this new procedure in several fresh cadaver studies, and in 2003 a patient with T3 N1 MO squamous cell carcinoma of the penis underwent the first ESMIL procedure [3]. Since our initial report, several teams around the world have reported on the utility of this procedure in the treatment and staging of penile, melanoma, and gynecologic cancers. In one series, the investigators performed ESMIL on one leg and a traditional open procedure on the opposite leg in 10 patients undergoing bilateral procedures, and ESMIL alone in five patients. They found no difference between the groups in the number of nodes removed: 10.8 in the ESMIL group and 9.7 in the open group. Complications were seen in 70% of the open cases and in only 20% of the endoscopic group. In the open cohort, skin-related complications were seen in five limbs and lymph complications in two patients. In the endoscopic patient group, skin-related complications were seen in one patient, hematoma in one patient, and lymphorrhea in one patient for 12 days with the drain in place. After the endoscopic dissection, all patients were discharged within 24 h. In the open group the average hospital stay was 6.4 days. At a mean follow-up of 31 months, there were no local or trocar site recurrences [4].

In a second series, 25 ESMIL procedures were performed in 16 patients for scrotal, penile, urethral or melanoma cancer. Both the superficial and deep nodes were removed in these patients; the average number of nodes removed was nine. Complications occurred in two patients, cellulitis in one and a seroma in

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the other. No patient suffered lymph edema or flap necrosis [5].

Indications/contraindications

ESMIL is indicated when traditional inguinal lymphadenectomy would be required for staging squamous cell carcinoma of the penis. Patients with nonpalpable nodes or small (<1 cm) mobile nodes at high risk for inguinal node involvement are considered good candidates for endoscopic node dissection. Approximately 10% of patients with pTa and pT1 grade I penile tumors will have positive nodes when inguinal nodes are not enlarged. Fifty percent of patients with pT2 tumors and grade III tumors will demonstrate positive inguinal lymph nodes.

Both stage and grade are predictive of nodal involvement. Verrucous carcinoma and carcinoma *in situ* are both associated with a low risk for nodal metastasis. However, 70% of stage T2 cancers have positive nodes. Grade I tumors have a 30% chance of spread to lymph nodes, while approximately 85% of patient with grade III tumors have inguinal node involvement [2]. Because cross drainage from the affected side to the contralateral side is a well-known occurrence, bilateral dissection is indicated in patients at high risk for metastatic disease (stage T2 or greater or grade II–III tumors).

Patients with large, fixed inguinal lymph nodes have a relative contraindication to ESMIL. In these patients it can be very difficult to dissect the superior aspect of fixed, matted lymph nodes with an endoscopic technique and as a result, they may be better candidates for traditional open surgery.

Preoperative preparation and evaluation

A complete metastatic evaluation should be performed prior to biopsy of the presenting penile lesion or partial penecotomy when indicated. The presence of carcinoma of the penis is established with biopsy to determine the diagnosis, extent of invasion, presence of vascular invasion, and grade of the lesion prior to lymphadenectomy. Distant metastatic disease without lymph node involvement is rarely seen. However, distant metastatic spread to bone, brain, liver, and lung should be considered as part of the overall work-up for penile cancer. Computed tomography of the pelvis and inguinal region can be helpful in determining the presence of large pelvic and inguinal nodes, especially in the obese patient.

Waist-high elastic stockings should be fitted prior to surgery. Preoperative intravenous antibiotics for skin flora coverage are given 60 min prior to the skin incision. A sterile preparation of the area is performed in the usual fashion.

Operating room configuration and patient position

The operating room (OR) is configured so that all staff can view the procedure. The surgeon's monitor is placed on the contralateral side of the dissection, near the shoulder and arm of the patient. A second monitor is placed on the opposite side in the case of bilateral dissection or as needed for viewing by the entire team.

The patient is placed in a supine position, with the ipsilateral knee flexed and hip abducted. The foot on the side of dissection is secured to the contralateral leg for a unilateral dissection or both feet are secured together for a bilateral procedure. A pad placed under the bent knee will help maintain the correct position (Figure 78.1).

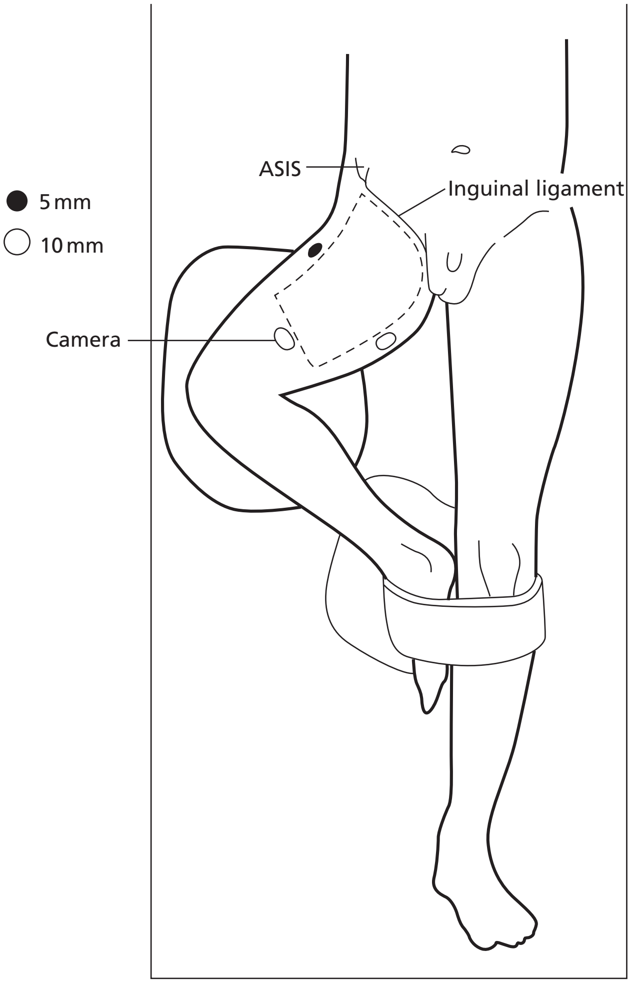

Figure 78.1 Patient is placed in a supine position, with the ipsilateral knee flexed and hip abducted (reproduced from Bishoff J.T., Kavoussi, L.R., eds. *Atlas of Laparoscopic Urologic Surgery.* Philadelphia: Saunders Elsevier, 2007, with permission).

Procedure

The key points are listed in Table 78.1.

Trocar placement

Before placing the first trocar, the limits of the dissection are marked on the skin. This important step will guide the surgeon by preserving the appropriate orientation once the skin becomes distorted from the insufflation used to create the working space. A line is drawn from the pubic tubercle to the anterior superior iliac crest. The width of the area of dissection is approximately 11–12 cm and the length 15 cm down the medial thigh and 20 cm down the lateral thigh (Figure 78.2).

Trocar placement is the same for the left and right sides. The trocars are placed just outside the delineated area of dissection. Initially, a 2.5-cm incision is made over the saphenous vein, 15 cm below the pubic tubercle. The incision is continued down to expose adipose tissue. It is important to avoid making the incision any larger than 2.5 cm to prevent CO_2 escape during the procedure, once the trocar is inserted and the subcutaneous cavity insufflated. A second 2.5-cm incision is made

Table 78.1 Key points in endoscopic subcutaneous modified inguinal lymph node dissection.

- Using an illuminated instrument or the light directed from the laparoscope will improve visualization of the initial dissection and establishment of the correct tissue planes during placement of the first two trocars
- Entry into the correct plane of dissection with scissors facilities dissection after trocars have been placedContinuous flow of CO_2 allows rapid clearing of water vapor or smoke during dissection in the small working space
- A working pressure of 5 mmHg is sufficient to maintain visualization while avoiding spontaneous infiltration beyond the boundaries of dissection
- The LigaSure 5-mm device offers excellent hemostasis, rapid dissection, and less need for evacuation of smoke or vapor compared to ultrasonic shears
- Key landmarks are readily identified and transillumination of the skin facilitates orientation
- Following the saphenous vein helps with identification of landmarks but as many branches as possible should be preserved to decrease lymph edema in the lower extremity
- All tissue should be divided with ultrasonic energy or electrocautery to decrease the incidence of prolonged lymphatic leak

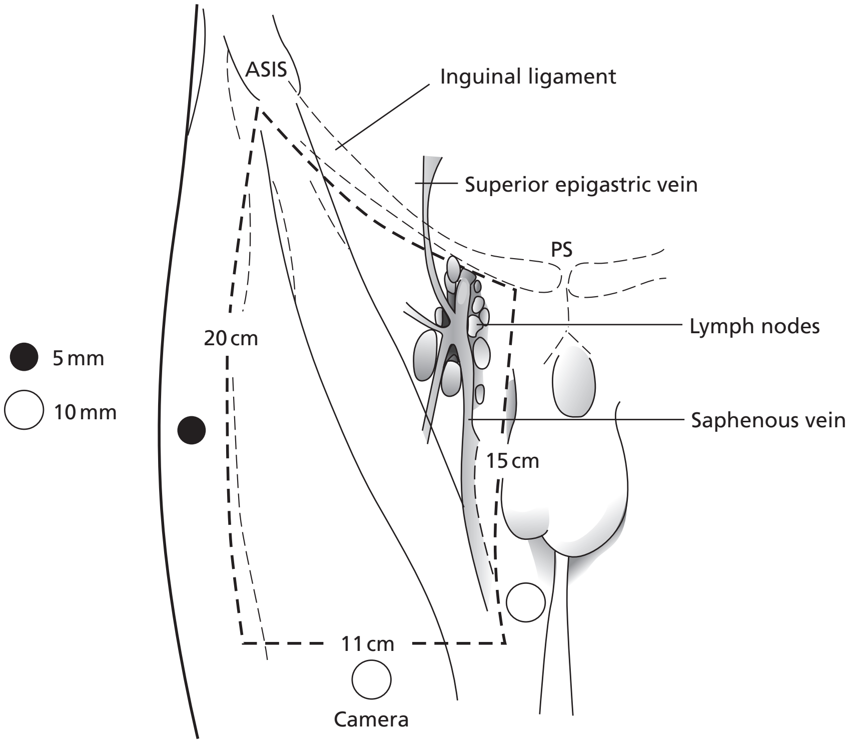

Figure 78.2 Limits of dissection are drawn on the skin (reproduced from Bishoff J.T., Kavoussi, L.R., eds. *Atlas of Laparoscopic Urologic Surgery.* Philadelphia: Saunders Elsevier, 2007, with permission).

in the center of the inferior boundary of dissection (Figure 78.2).

Before the two 10-mm blunt tipped trocars (Covidien, Autosuture, Mansfield, MA, USA) are placed, the surgeon uses these two incisions to establish the correct plane of dissection, working from one toward the other. Time spent doing this at the start of the procedure will significantly shorten the overall length of the procedure. Sharp, fine curved scissors are required in this next step. Elevating the skin with atraumatic forceps or skin hooks, the surgeon uses the fine scissors to dissect the fat packet from Scarpa's fascia underneath the skin side of the flap. Starting at the medial 10-mm trocar site (the first 2.5-cm incision), the dissection of the fat plane from the under surface of Scarpa's fascia extends superiorly along the medial aspect of the limit of dissection as far as the surgeon can see, and then extends laterally toward the second 2.5-cm incision that was placed inferiorly in the center of the lower limit of dissection. Care should be taken to avoid creating a hole in Scarpa's fascia and the skin. Using the curved side of the fine scissors with the tips pointed down will help in the dissection and decrease the chance of creating a skin hole during this part of the procedure. The laparoscope is a ready source of excellent illumination for the dissection and is more effective than overhead lights or head lamps. The developing node and fat packet will be dissected from Scarpa's fascia connecting the two trocars and extending as far superior as possible, given the limits of visualization, but usually 5–6 cm.

Attention is next directed towards finding the deep limits of dissection. This is an easier plane to exploit than that between the skin and Scarpa's fasica. At the inferior limit of the dissection, the nodal and fat packet is divided along the inferior margin or limit of dissection, and posteriorly to expose the external oblique aponeurosis and fascia lata. Once this plane has been developed it can quickly be advanced from the initial 2.5-cm incision site towards the second 2.5-cm incision site using the 5- or 10-mm LigaSure (Covidien, Boulder, CO, USA) bipolar cautery device to divide any perforating vessels. Once the inferior limit has been freed from the underlying fascia along the inferior margin of dissection, the same plane is dissected superiorly for 5–6 cm using the laparoscope to illuminate the field and the LigaSure for hemostasis. The dissection is then extended along the medial and lateral marked limits of dissection, progressively freeing the packet towards the upper or superior margins of dissection. This will help to expose the saphenous vein medially, which should be spared if possible.

Once the dissection has freed the packet from the lateral, medial, and inferior borders for a distance of 5–6 cm, a short 5-mm threaded trocar is placed in the lateral position (Figure 78.2) using the surgeon's finger as a guide. The two 10-mm blunt tipped trocars (Covidien) can now be placed in the two inferior 2.5-cm incisions, the balloons inflated, foam collars lowered into place to create an air-tight seal, and the insufflation tubing attached to the (noncamera) trocar. The blunt tipped trocar is ideal for this procedure since its unique internal balloon and foam collar create an excellent seal, while leaving a very small profile inside the area of dissection. The camera is placed through the middle inferior trocar site (Figure 78.2). The medial 10-mm trocar will become the working trocar, since it can accommodate a retrieval sac and larger instruments, such as the laparoscopic spoon forceps, to remove lymph node packets during the procedure.

The working space is insufflated to a pressure of only 5 mmHg. Higher pressures will not aid in the dissection but will result in subcutaneous spread of $CO_{2.}$

The 5- and 10-mm LigaSure devices are used to dissect the node packet. The bipolar device results in less visual obstruction compared to the water vapor emitted by ultrasonic shears, and consequently allows the dissection to proceed with fewer interruptions to clean the camera lens.

Dissection

Inguinal lymph nodes are divided into superficial and deep nodes. The superficial nodes are those located anterior to the fascia lata and the deep nodes are those located posterior to the fascia lata. The inguinal lymph node dissection is carried out 2 cm above the inguinal ligament superiorly, lateral to the sartorius muscle and medial to the adductor longus. The superficial nodes are located in four quadrants centered around the saphenofemoral junction: (1) nodes in the area of the superficial circumflex iliac vein; (2) nodes in the area of the superficial epigastric vein and the superficial external pudendal vein; (3) nodes located in the inferomedial quadrant around the saphenous vein; and (4) nodes around the insertion of the superficial circumflex iliac vein and the lateral accessory saphenous vein (Figure 78.3) [6].

The deep inguinal lymph nodes include the most cephalad node, known as the node of Cloquet, located in the area of the femoral vein and the lacunar ligament (Figure 78.4).

The dissection begins above Scarpa's fascia, anteriorly removing the tissue located between the skin and the fascia lata. Early in the dissection, the saphenous vein should be identified and preserved. If possible it is helpful to identify the borders of dissection medially at the adductor longus and laterally at the sartorius muscle edges. In some patients it can be difficult to identify these landmarks without opening the fascia lata, but the margins marked on the skin will help in the dissection of the superficial nodal tissue. Subcutaneous vessels and saphenous branches can be divided using ultrasonic

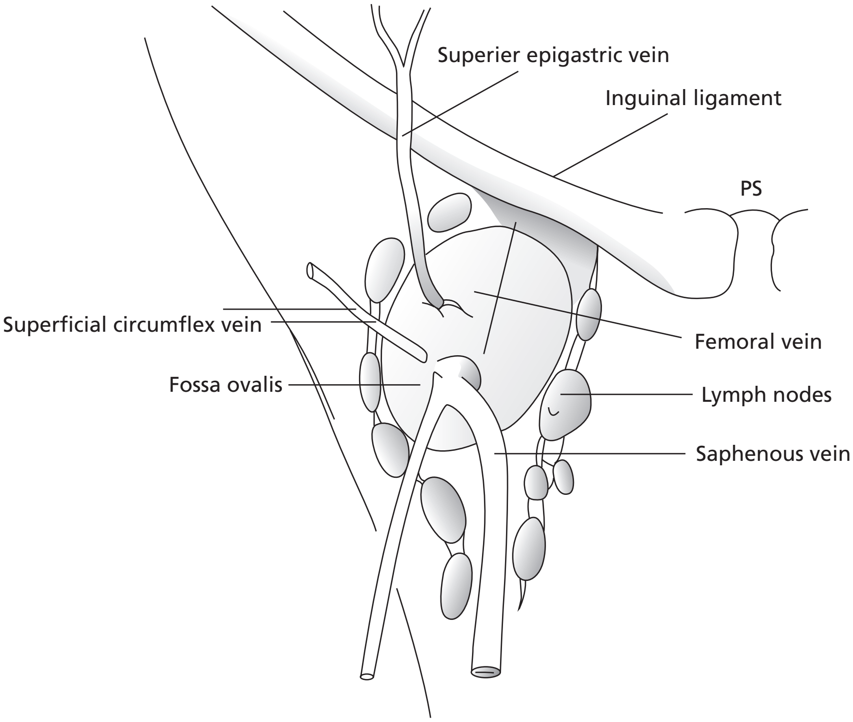
Superier epigastric vein
Inguinal ligament
PS
Superficial circumflex vein
Femoral vein
Fossa ovalis
Lymph nodes
Saphenous vein

Figure 78.3 Location of superficial nodes in four quadrants centered around the saphenofemoral junction (see text) (reproduced from Bishoff J.T., Kavoussi, L.R., eds. *Atlas of Laparoscopic Urologic Surgery.* Philadelphia: Saunders Elsevier, 2007, with permission).

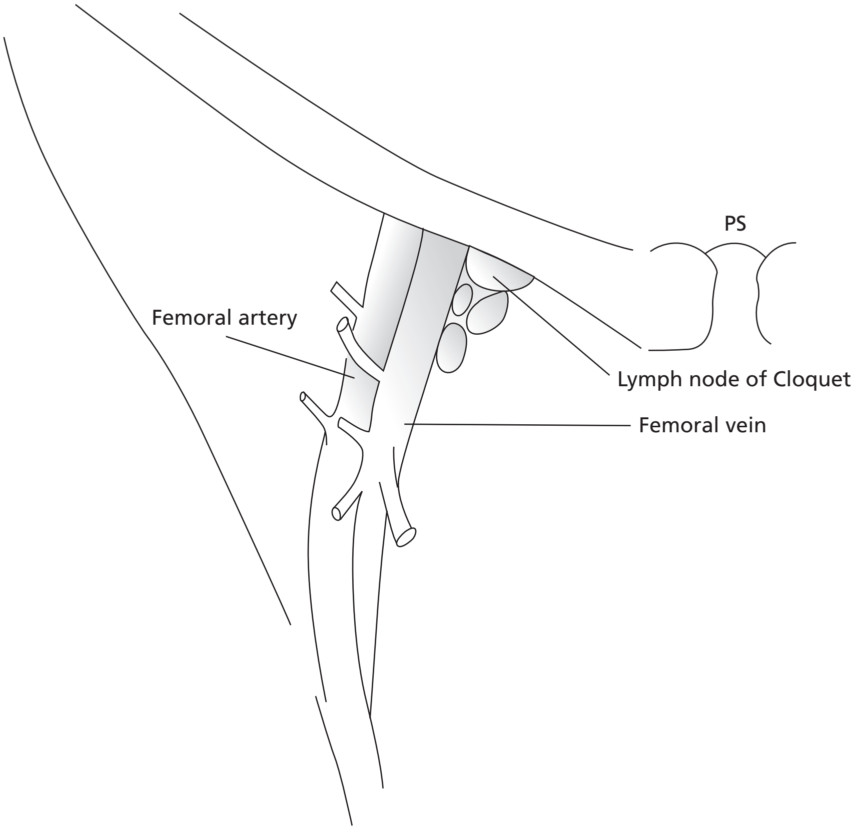
PS
Femoral artery
Lymph node of Cloquet
Femoral vein

Figure 78.4 Location of the node of Cloquet. PS, pubic symphysis (reproduced from Bishoff J.T., Kavoussi, L.R., eds. *Atlas of Laparoscopic Urologic Surgery.* Philadelphia: Saunders Elsevier, 2007, with permission).

energy or electrocautery. Lymph node-bearing tissue is dissected from the fascia lata to the fossa ovalis.

As the dissection progresses towards the inguinal ligament, the external ring is identified and the fat and lymphatics in the area of the cord to the base of the penis medially are removed. The lymph node dissection is continued for 3–4 cm superior to the inguinal ligament. Once the nodal tissue and fat are removed from the external oblique and the inguinal ligament, the femoral vessels will be identified inside the femoral sheath.

To gain access to the deep nodes, the fascia lata is opened to the edge of the adductor longus medially and the sartorius muscle laterally. The triangular-shaped lymph packet within the femoral triangle is carefully removed. Opening the femoral sheath down towards the apex of the triangle will reveal the deep lymph nodes. Medial dissection will free the node of Cloquet. Any residual tissue between the femoral artery and vein is removed. Care is taken to prevent injury to the femoral nerve by limiting the lateral dissection to the femoral artery.

If the skin overlying the exposed vessels appears to be compromised in any way, the sartorius can be mobilized from the anterior superior iliac crest, using ultrasonic or bipolar cautery, and transferred over the exposed vessels. Three or four size 2-0 PDS sutures are used to attach the sartorius muscle to the inguinal ligament.

The lymph node packet can be too large to extract through the initial skin incision. In this case the packet can be divided using the bipolar cautery device and extracted in two long strips. We recommend placing the nodes in an extraction sac to decrease the chance of inadvertent skin contamination. If a large nodal packet is placed in the extraction sac but cannot be extracted through the trocar, the balloon on the trocar can be deflated and the packet (secured inside the retrieval bag) can be extracted directly through the incision. In order to prevent seeding the trocar site, fatty and lymphatic tissue specimens should not be extracted directly through the skin incision without being placed inside an extraction sac. In the case of large specimens, the packet can be divided into two long strips for extraction.

At the end of the procedure a 7-mm Jackson–Pratt drain is placed inside the cavity to ensure drainage at the most dependent site of dissection. This can be placed through the 5-mm trocar site or a new site chosen as needed. The two 10-mm trocar sites are closed with skin adhesive or subcuticular sutures. Once the skin adhesive is dry, a circular bandage is placed around the surgical area and held in place with an elastic bandage for 24 h.

Postoperative management

The patient is discharged the day after surgery. Waist-high elastic stockings are worn for 2 weeks. Bed rest at home is recommended for 5–7 days with the lower extremities elevated. Low molecular weight heparin (Lovenox; Sanofi-Aventis, Bridgewater, NJ, USA) is started after surgery and continued until the patient is fully ambulant and the drain has been removed. The subcutaneous drain remains in place until daily output is less than 30 mL.

Table 78.2 Minor and major postoperative complications.

Minor
Local wound debridement in clinics
Mild-to-moderate leg edema
Seroma formation not requiring aspiration
Minimal skin edge necrosis requiring no therapy
Scrotal edema
Major
Wound infection
Severe leg edema interfering with ambulation
Skin flap necrosis requiring skin graft
Deep venous thrombosis
Re-exploration or other invasive procedure performed in the operating room
Death

Complications

The diagnostic and therapeutic benefits of early inguinal lymphadenectomy should be measured against the potential morbidity associated with the procedure [7, 8]. Patients should be aware of the minor and major postoperative complications associated with this procedure (Table 78.2).

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CHAPTER 79

Laparoscopic Retroperitoneal Lymph Node Dissection

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Introduction

Testicular cancer is the most common malignancy in men aged 15–35 years [1]. Fortunately, survival rates for men with testicular cancer are excellent, largely based on a multidisciplinary treatment approach incorporating surgery, radiation and cisplatin-based chemotherapy. Retroperitoneal lymph node dissection (RPLND) has an important diagnostic and therapeutic role in the management of men with testicular cancer. Although RPLND is used in the management algorithm for seminoma patients with residual positron emission tomography (PET)-positive masses following chemotherapy, the overwhelming majority of RPLNDs are performed in patients with nonseminomatous germ cell tumors (NSGCTs) and therefore this patient population will be the focus of this chapter.

There is a well-defined treatment algorithm for patients with NSGCTs based on both stage and risk of disease recurrence [2]. Within this treatment paradigm, surgical management in the form of RPLND maintains a critical role. The rationale for RPLND in the management of NSGCTs includes a highly predictable pattern of lymphatic spread to the retroperitoneum, the potential for RPLND to be curative in patients with low-volume retroperitoneal disease, and the 20–30% false-negative rate in the radiographic staging of patients with clinical stage I disease [3].

Traditionally, RPLND has been performed by way of an open incision, with most preferring a midline approach. With the increasing popularity of minimally invasive surgery, surgeons have been expanding the application of such approaches to the treatment of more complex disease processes. Minimally invasive surgery offers the advantage of decreased blood loss, less pain, improved cosmesis, and shorter convalescence times; however, it should be noted that the oncologic efficacy of any cancer procedure is paramount and should not be compromised in an effort to expand the application of minimally invasive surgery. With this in mind, it should be noted that open RPLND has proven excellent long-term oncologic outcomes, and therefore laparoscopic RPLND should be performed with the goal of improving patient quality of life, while replicating the oncologic efficacy of the open approach.

Laparoscopic RPLND has not gained widespread acceptance as readily as other minimally invasive urologic procedures, such as laparoscopic nephrectomy and robotic prostatectomy. The rationale for this is likely twofold. First, laparoscopic RPLND is a technically demanding operation which requires dissection around major vascular structures and therefore is limited to those with extensive laparoscopic experience. Second, laparoscopic RPLND was used as a staging procedure in many initial reports without attempting to replicate the open technique. In such series, RPLND was aborted in favor of chemotherapy if positive lymph nodes were encountered and thus was performed for staging purposes [4–6]. As laparoscopic skills have evolved, techniques for laparoscopic RPLND have also matured. Laparoscopic RPLND is now being performed within specialized centers with therapeutic intent; with bound-

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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aries of dissection identical to those of the open approach.

Rationalein patients with Stage I and II nonseminomatous germ cell tumors

Despite negative cross-sectional imaging, 25% of patients with stage I NSGCT will harbor occult malignancy in the retroperitoneum [3]. RPLND can accurately stage the retroperitoneum, identifying patients with metastatic disease despite negative imaging. The vast majority (>90%) of patients with pathologic stage I disease will be cured with RPLND alone. In patients with a low tumor burden, RPLND spares patients the toxicity and potential long-term morbidity of systemic chemotherapy [7]. The retroperitoneum is also the most frequent site of chemoresistant malignant germ cell tumor and teratoma, both of which can be effectively controlled with RPLND [8, 9]. RPLND is also advocated in men with teratoma in the orchiectomy specimen, as this may increase the likelihood of retroperitoneal teratoma which is chemoresistant [8, 9].

Patients with clinical stage II NSGCTs can also benefit from RPLND. Patients with stage IIa disease can potentially forgo additional treatment in the form of chemotherapy as up to 70% will be cured with surgery alone [10]. The risk of relapse following RPLND is directly related to the extent of disease found in the retroperitoneum. Patients with pN2 or pN3 disease have relapse rates of 50% and therefore adjuvant chemotherapy should be strongly considered in those patients [11].

Templates

Retrograde ejaculation is a significant concern for young men who undergo RPLND. Earlier outcomes with non-nerve-sparing bilateral RPLND reported significant retrograde ejaculation rates. The relatively predictable and consistent pattern of lymphatic spread of testicular tumors, along with mapping studies to identify the most common areas of retroperitoneal metastasis, led to the concept of RPLND templates in an attempt to minimize the potential for retrograde ejaculation [12–14]. Such templates minimize dissection in retroperitoneal areas in which metastatic disease would be unlikely. Unilateral templates avoid dissection below the level of the inferior mesenteric artery, minimizing sympathetic nerve fiber damage in this region. Avoidance of dissection of efferent sympathetic fibers emanating from the contralateral sympathetic trunk also reduces the risk of retrograde ejaculation. Antegrade ejaculation is reported in approximately 90% of patients undergoing modified template RPLND [15, 16].

With further improvements in surgical technique, nerve-sparing techniques have been employed. The sympathetic trunks, postganglionic sympathetic nerve fibers, and hypogastric plexus can be prospectively identified at the time of RPLND and preserved. In doing so, ejaculatory function can be preserved in approximately 95% of men undergoing this procedure [17]. This technique offers the advantage of a bilateral dissection without compromising ejaculatory function and has replaced the use of template dissections at some centers.

Stage I nonseminomatous germ cell tumors

Critics of laparoscopic RPLND cite early series which used this technique as a staging procedure without intention of replicating open RPLND. In the setting of metastatic disease, laparoscopic RPLND was aborted and patients were given chemotherapy. Contemporary laparoscopic series have moved towards replicating open RPLND both in its therapeutic intent and extent of dissection. This includes the use of bilateral dissections, retroaortic/retrocaval lymphadenectomy, and limiting the use of chemotherapy in patients with low-volume stage II disease. While adhering to strict oncologic principles, laparoscopic RPLND offers the advantage of decreased patient morbidity.

Early and intermediate outcomes for laparoscopic RPLND have been reported from multiple centers (Table 79.1) [18–23]. These studies confirm that laparoscopic RPLND is feasible and safe. Open conversion rates have proven to be low, with uncontrollable bleeding being the most common reason for conversion to an open procedure. Mean operative times range from 138 to 261 min, with mean length of stay ranging from 1.6 to 6 days. Mean blood loss range from 50 to 145 mL. For patients with pN0 disease, retroperitoneal recurrences are rare when laparoscopic RPLND is performed with therapeutic intent. The long-term oncologic efficacy of laparoscopic RPLND remains to be proven. As discussed previously, the significant majority of patients from initial laparoscopic RPLND series received adjuvant chemotherapy and therefore the oncologic efficacy of the surgical procedure cannot be determined. More contemporary series have reported outcomes for patients found to have node-positive disease at the time of therapeutic laparoscopic RPLND with promising early results. In the three series in which chemotherapy was not administered to node-positive patients, there have been no recurrences within the boundaries of the RPLND template. Skolarus *et al*. reported one patient in their series with pathologic stage IIA disease who had no evidence of disease 31.3 months following laparoscopic RPLND [22]. Nielsen *et al*. reported on 10 pathologic stage IIA patients who were observed without chemotherapy after laparoscopic RPLND. Recurrences were seen in two (20%) patients (one biochemical, one

Table 79.1 Contemporary laparoscopic retroperitoneal lymph node dissection series for patients with stage I nonseminomatous germ cell tumors.

Series	N	Follow-up (months)	OR time (min)	Open conversion (%)	Length of stay (days)	EBL (mL)	Node positive	Adjuvant chemotherapy	p0 Recurrences
Guzzo *et al.* 2010 [23]	26	23	185	3.8	2	100	9	4	1 pulmonary 1 penile corpora
Steiner *et al.* 2008 [24]	42	17	323	0	4.8	125	5	0	1 pulmonary
Cresswell *et al.* 2008 [21]	79	84	177	1.3	6	NR	19	19	3 pulmonary 2 RP outside template 2 biochemical 1 port site
Skolarus *et al.* 2008 [22]	19	23.7	250	0	1.5	145	6	5	0 RP
Nielsen *et al.* 2007 [19]	120	29	NR	NR	NR	NR	46	36	2 pelvic outside template 4 pulmonary 1 biochemical
Neyer *et al.* 2007 [18]	136	68	261	5.1%	4.1	50	25	25	6 pulmonary 1 biochemical 1 RP outside template
Albqami *et al.* 2005 [20]	103	62	217	2.9%	3.6	144	26	26	1 RP outside template 3 pulmonary 1 biochemical

OR, operating room; EBL, estimated blood loss; NR, not reported; RP, retroperitoneal.

pulmonary) following laparoscopic RPLND and were salvaged with chemotherapy. The remaining eight patients were without evidence of disease at a mean follow-up of 37 months [19]. Guzzo *et al.* have also reported on four patients with pN1 disease who did not receive adjuvant chemotherapy and who were without evidence of disease at a mean follow-up of 23 months [23]. More recently, Steiner *et al.* have reported their experience with bilateral nerve-sparing laparoscopic RPLND in 21 clinical stage I NSCGT patients, five (24%) of whom were found to have pathologic stage IIA disease [24]. None of the five patients was given adjuvant chemotherapy and all were without recurrence at follow-up intervals of 2–35 months. Additionally, no retroperitoneal recurrences were noted in patients who had pathologically confirmed stage I disease, implying that an adequate dissection was performed.

Clinical stage II nonseminomatous germ cell tumors and post chemotherapy

Limited evidence exists regarding the role of laparoscopic RPLND for patients with stage II disease. Several studies have reported outcomes for laparoscopic RPLND in the postchemotherapy setting. Albqami *et al.* have reported their experience with 59 patients with stage IIB or IIC disease who have undergone postchemotherapy laparoscopic RPLND [20]. No open conversions were reported in this patient population. Of the 43 patients with preoperative stage IIB disease with a mean follow-up of 53 months, one experienced a recurrence 24 months postoperatively along the external iliac nodes, outside the original template. Maldonado-Valadez *et al.* have also demonstrated the feasibility of postchemotherapy laparoscopic RPLND in a small number of patients ($n = 16$), reporting no open conversions or blood transfusions [25]. Viable tumor was found in three (19%) patients, of whom two received additional adjuvant chemotherapy. Of concern, two patients with viable tumor experienced a recurrence. The first was noted to have an enlarged renal hilar lymph node at his first 3-month postoperative follow-up. This was managed with repeat laparoscopic RPLND and the final histology revealed only necrosis. The second patient had a retroperitoneal recurrence 11 months postoperatively and ultimately died of his disease despite salvage chemotherapy. These two series are concerning from an oncologic perspective given the fact that a full bilateral RPLND was not performed [20, 25], which is generally considered standard of care in the postchemotherapy setting for NSGCT patients [26]. Although these authors reported that postchemotherapy RPLND was safe, others have reported open conversion rates as high as 29% and 67%, and overall complication rates greater than 50% [5, 27]. Given the high potential for complications in postchemotherapy patients, laparoscopic RPLND should only be attempted in highly selected patients by surgeons with significant laparoscopic experience who are comfortable with open RPLND if conversion is needed.

Keeping in line with the goals of open postchemotherapy RPLND, Steiner *et al*. have performed bilateral nerve-sparing laparoscopic RPLND on 19 postchemotherapy patients with stage IIB disease [24]. The authors found teratoma, necrosis/fibrosis, and active tumor in four, 14, and one patient, respectively. Laparoscopic RPLND was also performed in two patients with clinical stage IIA disease who did not undergo chemotherapy. No retroperitoneal recurrences were noted in either group at 17 months follow-up.

Surgical technique

Laparoscopic RPLND is a technically demanding procedure and therefore should only be performed by surgeons experienced in complex laparoscopic surgery. Additionally, experience with laparoscopic vascular techniques and open RPLND is also advised in case of inadvertent vascular injury or the need for open conversion arises.

Preoperative patient preparation

Appropriate preoperative counseling should include all options for management, including open RPLND, chemotherapy, and surveillance when appropriate. Preoperative sperm banking should be discussed prior to surgery. The potential for open conversion either in the setting of intraoperative complication or extensive disease should also be discussed prior to surgery. Some surgeons recommend a low-fat diet 1–2 weeks prior to surgery to reduce the risk of chylous ascites; however, evidence for such an approach is lacking. Patients should be placed on a clear liquid diet 48 h prior to surgery and undergo a mechanical bowel preparation the day prior to surgery. Preoperative antibiotics are given prior to surgery, and antiembolism compression stockings and sequential compression devices are placed on the lower extremities to minimize deep vein thrombosis.

Positioning and port placement

General endotracheal anesthesia is required, as the patient must remain paralyzed throughout the case. Prior to insufflation, an orogastric tube and Foley catheter should be placed. The patient can be placed in the modified flank (similar to that for laparoscopic nephrectomy) or supine position. We prefer to place patients supine with both arms tucked, as this does not require repositioning if a bilateral RPLND is needed. All pressure points should be padded to minimize the risk of nerve palsy. Patients should be secured to the operating room table both with a seat belt and tape as the table is often maximally rotated to either side to facilitate bowel retraction (Figure 79.1).

A transperitoneal approach is the preferred method due to the larger and more anatomically familiar working space for most urologists. A retroperitoneal approach can be performed; however, doing so precludes bilateral

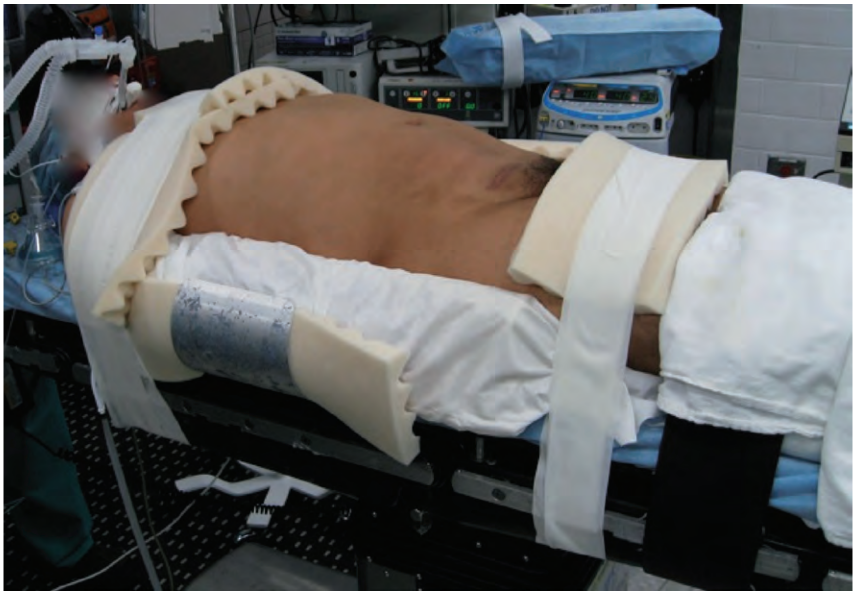

Figure 79.1 Supine positioning for laparoscopic retroperitoneal lymph node dissection.

dissection from the same port placement [28, 29]. Using a transperitoneal approach, peritoneal access is obtained via either Veress needle placement or Hasson technique. The peritoneal cavity is then insufflated to $15\,\mathrm{cmH_2O}$ at which point four evenly spaced 10/12-mm laparoscopic ports are placed in the midline. The most superior port should be placed approximately 2 cm below the xiphoid process. It is important to maintain uniform spacing between the ports and thus a trocar may not always be located at the level of the umbilicus, depending on patient body habitus. A 10/12-mm port should be used for each site to allow instrument versatilty from a variety of working angles to cover the entire retroperitoneum. Once all ports are in place, the bed is rotated to assist in medialization of the bowel.

Right-sided dissection

The white line of Toldt is incised in a manner similar to that for a laparoscopic nephrectomy. The peritoneal incision is carried further inferiorly in order to completely expose the inferior border of the RPLND template and the spermatic cord. The duodenum is then kocherized, allowing for wide exposure of the retroperitoneum and great vessels. The ureter should be identified early during the course of dissection to minimize inadvertent injury.

The spermatic cord dissection is generally performed using the three most inferior ports, placing the camera in the middle. The peritoneum is incised medial to the spermatic cord and the vas deferens is transected to allow further mobilization. It is useful to place a clip on the gonadal vein proximally, which will minimize blood loss in the event of inadvertent avulsion. The spermatic cord can then be grasped and dissected inferiorly toward the internal ring. The peritoneum is then incised circumferentially around the internal ring. Retraction of the spermatic cord exposes fibrous attachments and greatly aids dissection. The dissection is carried inferiorly until the orchiectomy suture is encountered. The entire distal spermatic cord is then excised. The cord can then be followed proximally to the inferior vena cava (IVC) and ligated. The specimen can then be placed in an EndoCatch bag to be retrieved at the end of the case (see Video 79.1).

In general the right-sided template involves removal of the right common iliac, paracaval, interaortocaval, preaortic, and medial para-aortic lymph nodes. The lymphadenectomy is best started using the superior three ports with the camera port in the middle. Bowel mobilization can be greatly aided by placing a paddle retractor through the most inferior port, which can be held by the assistant surgeon. The tissue overlying the IVC is carefully incised longitudinally, allowing for a split and roll technique (see Video 79.2). A combination of blunt and sharp dissection can be used to carry this plane inferiorly over the common iliac vessels and superiorly to the renal hilum. Attention should be paid to the presence of lower pole accessory renal arteries, which can cross the IVC anteriorly. All fibroadipose tissue is then dissected free from the renal vessels to the junction of the IVC. The lateral extent of this packet is dissected free to the ureter and then followed down to the common iliac vessels. This packet can then be clipped and divided at the junction of the iliac vessels and placed in an endoscopic bag.

The medial border of the previously incised tissue of the IVC is then grasped and "rolled" medially the entire length of the infrahilar IVC. In doing so, the retrocaval space is exposed and dissected. Cautious dissection is important at this point to identify lumbar veins, which are clipped and divided, allowing for complete mobilization of the IVC and dissection of the posterior lymphatic packet. Lumbar vessels should be clipped, leaving space along the IVC between the clip in the event that a clip is displaced (see Video 79.3). In doing so, the vessel can be grasped on the caval side and controlled to avoid hemorrhage. Uncontrolled lumbar vessels that retract into the iliopsoas can generally be controlled with pressure and a figure-of-eight suture. If a bilateral RPLND is being performed, the postganglionic nerve fibers should be identified and dissected free from the lymph node packet prior to its release. Next the aorta is identified and the anterior tissue is split in a similar fashion to that of the IVC to the level of the inferior mesenteric artery (IMA) inferiorly and the renal hilum superiorly. The interaortocaval node packet is then rolled medially and completely dissected free (see Video 79.2). Finally, the para-aortic node packet is dissected to the level of the IMA, completing the dissection.

Left-sided dissection

Similar to the right-sided dissection, the white line of Toldt is taken down sharply. It is important to completely free up the lateral attachments of the spleen to obtain wide exposure of the retroperitoneum. The distal spermatic cord dissection is performed in a similar fashion to that of the right-sided technique. The spermatic cord can then be dissected proximally to its insertion in the left renal vein and ligated. If necessary, lumbar veins draining into the renal vein can be clipped and divided in order to achieve complete renal hilar dissection. The renal vein can then be followed to its insertion into the IVC, removing all nodal tissue. The renal artery is also completely dissected. It is advisable to use clips in the area of hilar dissection to minimize the risk of postoperative chylous ascites.

The tissue overlying the aorta is then split as described above for the right-sided dissection. If nerve sparing is intended, care should be taken to identify the postganglionic sympathetic nerves overlying the aorta, which can be dissected free from the nodal packet (see Video 79.4). Laterally, the ureter is identified and all lymph node tissue is removed from its border down to the common iliac vessels. The previous split preaortic packet can then be rolled medially. With medial mobilization of this packet, the lumbar arteries will be encountered, which can be clipped and divided, allowing for dissection of the retroaortic space. As detailed previously, the tissues over the IVC can then be split to allow dissection of the paracaval, precaval, and interaortocaval lymph node packets.

Lymph nodes can be placed in a laparoscopic sac during the course of the operation. We typically place each lymph node packet in a separate laparoscopic sac; however, the use of multiple endoscopic retrieval sacs does add cost to the procedure. With the dissection complete, the retroperitoneum should be irrigated and hemostasis ensured. If large lymphatic leaks are identified, they should be ligated with clips. The bowel and adjacent organs should be inspected prior to closing the laparoscopic ports. The endoscopic bags can generally be retrieved through the trocar sites without having to extend the fascia. The trocar sites can then be closed using a laparoscopic fascial closure device. We typically do not leave a drain.

Bilateral laparoscopic dissection

Bilateral dissection may be performed when necessary and can be usually undertaken without a change in patient positioning. When the side of the primary tumor is completed with the templates described, a small amount of tissue is left just medial to the contralateral ureter and inferiorly towards the common iliac vessels. These tissues are dissected free and a bilateral dissection is completed.

Postoperative care

Patients are managed immediately after surgery without gastric decompression. Subcutaneous heparin injection can be administered on the evening of surgery. Clear liquids can be started the evening of surgery and patients can be advanced to a regular diet on postoperative day 1. Postoperative tachycardia can occur due to sympathetic stimulation and can be managed expectantly [30]. If bowel function has returned, patients can be discharged the afternoon of postoperative day 1. Some surgeons recommend a low-fat diet for several weeks postoperatively to minimize the risk of chylous ascites.

Complications

Laparoscopic RPLND is a technically challenging procedure associated with a steep learning curve. When performed by experienced surgeons, open conversion rates and perioperative complications are acceptable. The most common reason for open conversion is uncontrollable bleeding or vascular injury [31–33]. In contemporary series, the open conversion rate is less than 5%; however, open conversion rates have been reported to be as high as 11.8% [18–23, 34]. Surgeons should be experienced with operating around major vascular structures and laparoscopic hemostasis techniques to minimize the need for open conversion at the time of laparoscopic RPLND. Several hemostatic maneuvers, including increasing the pneumoperitoneum pressure, laparoscopic sponge pressure, use of hemostatic agents, and laparoscopic suturing techniques can all be used to control bleeding in the event of inadvertent vascular injury. Conversion to an open procedure should not be viewed as a failure and surgeons should be comfortable with the open technique in case open conversion is required. Injury to major abdominal viscera has been reported, but is rare [18, 33]. Open conversion and vascular injury rates have been reported to be higher in the postchemotherapy setting due to significant fibrosis which can obliterate normal anatomic planes [5, 27, 33].

Postoperative complications have been reported at a rate of 9.4–25.7% in contemporary series [18–23]. Reported complications include chylous ascites, ileus, lymphocele, nerve injury, pulmonary embolus, *Clostridium difficile* colitis, retroperitoneal hematoma, and urinoma [33]. Retrograde ejaculation is a potential long-term source of morbidity for patients undergoing both open and laparoscopic RPLND. Fortunately, the rates of retrograde ejaculation have been consistently low with the laparoscopic approach and range from 0% to 4.8% [18–23]. The incidence of retrograde ejaculation is higher in postchemotherapy laparoscopic RPLND patients, again due to dense fibrotic reaction which makes dissection and preservation of the nerves extremely challenging.

There is little information regarding prospective quality-of-life (QOL) outcomes for patients undergoing laparoscopic RPLND. A decreased analgesic requirement and time to resumption of oral intake has been reported in laparoscopic RPLND patients compared to those undergoing an open procedure [35]. This same cohort of patients also returned to their preoperative baseline QOL scores significantly faster than those undergoing open RPLND.

Conclusions

Laparoscopic RPLND has been demonstrated to be a feasible, safe, and effective treatment option for men with clinical stage I NSGCT at large volume institutions with experienced laparoscopic surgeons. Laparoscopic RPLND has evolved into a therapeutic operation duplicating the open procedure, with early reports demonstrating efficacy and minimal morbidity. Data regarding laparoscopic RPLND for clinical stage II disease and for patients who have received chemotherapy are limited and larger cohorts of patients with longer term follow-up are required to define the exact role of laparoscopic RPLND in this setting.

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CHAPTER 80

Laparoscopic Varicocelectomy

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Introduction

Varicoceles have been associated with progressive deterioration of testicular function and testicular hypotrophy. This is duration dependent and varicocele repair can stop or reverse this progression [1–6]. Most of the early scientific literature focused on infertility in adults; however, pediatric varicoceles are often identified by their physical appearance, e.g. the "bag of worms," during investigation of size asymmetry, or as incidental findings on examination or sonographic evaluation for other reasons. Pain is a much more common presentation in adults as compared to adolescents. Correction of varicoceles in the adolescent population has centered on asymmetric testicular growth. Correlations have been suggested between testicular hypotrophy and sperm concentration and motility [7, 8], and the logical assumption is that this affects future fertility.

Varicocelectomy has evolved over the years with three main approaches: microsurgical subinguinal (Goldstein), inguinal (Ivanissevich), and abdominal (Palomo, nonartery sparing). Intraluminal approaches, such as surgical antegrade sclerosis, which has been gaining in popularity particularly in Europe, and radiographic retrograde embolization, have also been utilized and studied. Laparoscopic varicocelectomy was introduced in 1990 [9] with more detailed description shortly thereafter [10–12]. Variations and refinements of the technique occurred over the ensuing years, and it was more frequently described in the pediatric literature.

One contentious issue is whether or not it is necessary to preserve the testicular artery. No significant difference has been found between artery-sparing techniques and the Palomo technique with regards to testicular growth [13, 14]. Some argue that the Palomo technique is associated with less persistence of varicoceles after repair due to the ligation of the small veins intimately associated with the testicular artery (0% vs 11%) [15]. Despite the higher recurrence associated with artery-sparing techniques, Zampieri *et al*. believe that preservation of the testicular artery leads to better improvement of semen parameters [16]. The results from initial series may reflect the limited access at the time to the higher definition, greater magnification laparoscopes, whereas now these are widely used to identify the accessory veins adherent to the artery. A recent addition to the armamentarium for artery-sparing varicocelectomy is a variety of Doppler transducers for laparoscopic use.

Sparing of the lymphatics (facilitated by laparoscopic magnification) has been shown to decrease the incidence of postoperative hydrocele formation [17, 18] compared to the similar open technique in subinguinal microscopic varicocelectomy [19–21]. Nonartery-sparing techniques have a higher incidence (~30%) of postoperative hydroceles because of lymphatic injury [14, 22, 23], although only 5% ultimately go on to require hydrocelectomy [14].

Advantages and disadvantages

The increased magnification afforded the surgeon with laparoscopy allows for accurate identification of vessels,

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lymphatics, which give rise to hydroceles if ligated, and the internal spermatic artery [17, 24]. In a recent analysis, laparoscopic varicocelectomy appeared to be safe in patients who had had prior inguinal surgery [25]. Suprainguinal access allows for high ligation of fewer veins compared to a more technically difficult and longer subinguinal microscopic approach. The laparoscopic approach offers a distinct advantage for bilateral varicoceles, as no additional incision is needed.

The main disadvantages of laparoscopic varicocelectomy are the same as those inherent to all laparoscopic surgery. Like all new techniques, there is a learning curve. How steep this learning curve is depends on the relative experience of the surgeon. For a surgeon already familiar with laparoscopic techniques, varicocelectomy using this approach is usually not difficult to master. The laparoscopic technique is more invasive than open varicocelectomy. Laparoscopic entry with the initial trocar for establishing the pneumoperitoneum runs the risk of perforation of major blood vessels, bowel, or bladder. Moreover, injury to the inferior epigastric vessels is a known risk with trocar placement. These risks are not associated with open varicocelectomy.

Anatomy [26]

The venous drainage of the testicle and epididymis can be divided into two systems. The predominant venous drainage system consists of the anterior spermatic or pampiniform plexus, responsible for draining the testis and anterior epididymis, and the testicular vein, which drains into the inferior vena cava on the right and the left renal vein on the contralateral side. The early branches of the testicular vein are the primary site of ligation in laparoscopic varicocelectomy.

An ancillary venous system is comprised of the posterior spermatic plexus or funicular veins, which drains the posterior epididymis, terminates in the inferior epigastric vein, and eventually empties into the external iliac vein, and the deferential veins that ultimately drain into the hypogastric vein via the superior vesical vein. In addition, the cremasteric or external spermatic vein drains into the saphenous system via the pudendal vein.

It should be kept in mind that there is a complex intercommunication between both the systems and the individual veins, and there exists substantial anatomic variation.

Indications

The indications for operative repair are persistent or recurrent scrotal pain, and as part of the treatment for subfertility. In adolescents, size discrepancies ranging between 10% and 20%, with the left testicle smaller than the right, have been proposed as cut-offs for significant asymmetry. In the pursuit of early treatment in adolescents with varicoceles to prevent the consequent development of infertility, recent evidence indicates that testicular asymmetry of greater than 20% or high peak retrograde venous flow of 38 cm/s or greater are prognostic indicators for persistent asymmetry and hence potentially abnormal semen analyses [27].

Operating room set-up

The patient should empty his bladder prior to entering the operating room. This avoids the need for urethral catheterization. He should be positioned supine on the operating room table. General anesthesia is induced. After adequately securing the patient to the table, the table is rotated 20–30° to elevate the affected side. Mild Trendelenburg will help allow the bowel to fall away from the pelvis.

The surgeon stands on the side contralateral to the side of the varicocele, and the assistant stands on the ipsilateral side.

The required instruments are listed in Table 80.1.

Trocar placement and technique

The landmarks for trocar placement are the umbilicus, pubic symphysis, and anterosuperior iliac spine.

Trocar placement for laparoscopic varicocelectomy involves many techniques incorporating anywhere from a single port [28] to three ports [29, 30]. The various approaches to access, such as transperitoneal versus retroperitoneal or closed versus open, are described in more detail in Chapters 74 and 75. Three-port transperitoneal access is described here (Figure 80.1), and we prefer to use the VersaStep™ Veress needle/radially expanding sheath system for initial access. This needle/sheath unit is passed through a curvilinear supraumbilical incision into the peritoneum (Figure 80.2).

Table 80.1 Instruments.

Scalpel blade
Electrocautery
5-mm trocar Set
VersaStep™ radially expanding/bladeless trocar system
30° lens/camera
Maryland dissector (Mediflex®)
Laparoscopic endoshears
LigaSure™ (Valleylab, Boulder, CO, USA), vascular sealing system
Laparoscopic Doppler

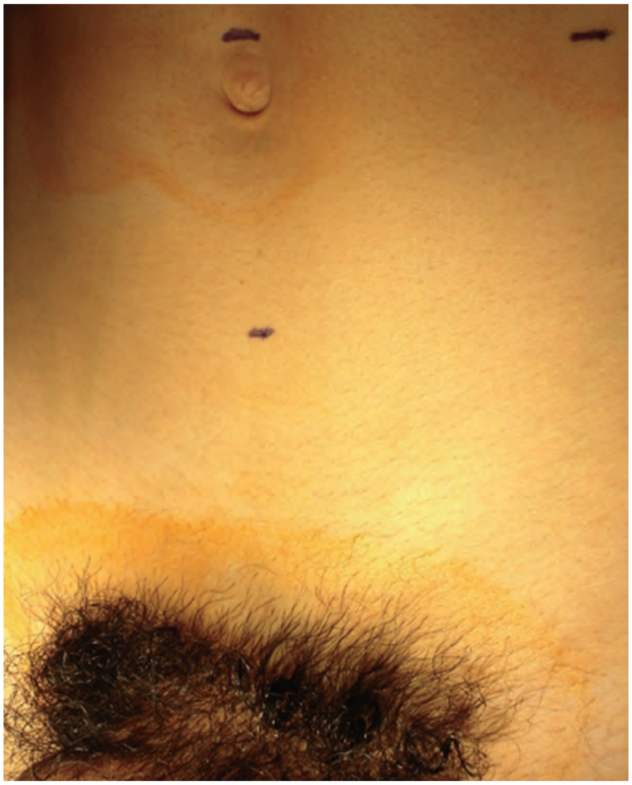

Figure 80.1 Port placement: 5-mm supraumbilical trocar for camera and insufflation, 5-mm trocar half way between the umbilicus and pubic symphysis in the midline, and 5-mm trocar on the ipsilateral side of the varicocele, lateral to the epigastic vessels.

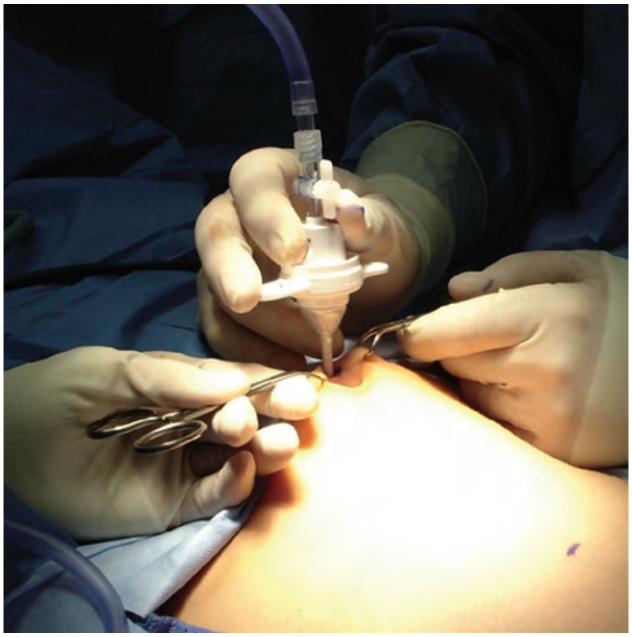

Figure 80.2 Veress needle/sheath placement into peritoneum through supraumbilical incision.

Once proper positioning is confirmed, the Veress needle is removed, leaving the sheath in place. A pneumoperitoneum of 15 mmHg is achieved, and the 5-mm trocar is advanced through the nonslip sheath. This serves as the laparoscope port. A 30° lens is inserted and under direct vision, a second 5-mm trocar is placed half to two-thirds of the way between the umbilicus and pubic symphysis in the midline. A third 5-mm port is placed on the side ipsilateral to the side of the varicocele and lateral to the epigastric vessels in line with the umbilicus.

In cases of bilateral varicocele, the positions of the trocar sites are the same for the first approached varicocele. For the contralateral side, the camera may be moved to the lateral port, if desired, and the two midline ports can serve as the working ports.

Exposure is obtained through the 5-mm supraumbilical port with the use of the 30° laparoscope to define the anatomy. The intrascrotal spermatic cord can be pulled to clarify the internal spermatic cord and its associated veins. By identifying and following the vas deferens, the internal ring is visualized (Figure 80.3).

The peritoneum wall is grasped proximal to where the vas deferens joins the cord (~5 cm) with the Maryland dissectors and the posterior peritoneum is incised with endoshears just anterolateral to the cord (Figure 80.4). The peritoneal window is extended inferiorly and medially.

A large vein is usually identified first anterolaterally (Figure 80.5). After isolating the vein with the Maryland dissector, it is ligated and divided using the LigaSure device (Figure 80.6). The use of this device avoids the need for multiple vascular staples to ligate each vein individually. Using two Maryland dissectors, any visible remaining veins are dissected while separating, if desired, the spermatic artery from them. These can be

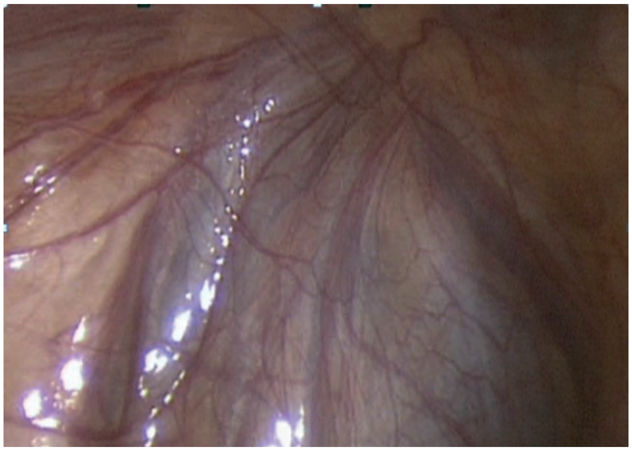

Figure 80.3 Visualization of the internal inguinal ring with convergence of the internal spermatic vessels (A) and vas deferens (B).

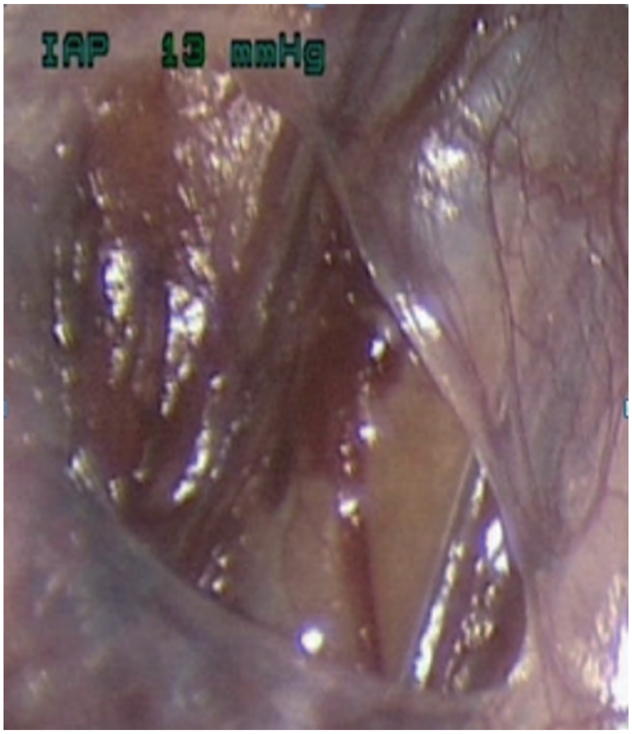

Figure 80.4 Incised posterior peritoneum.

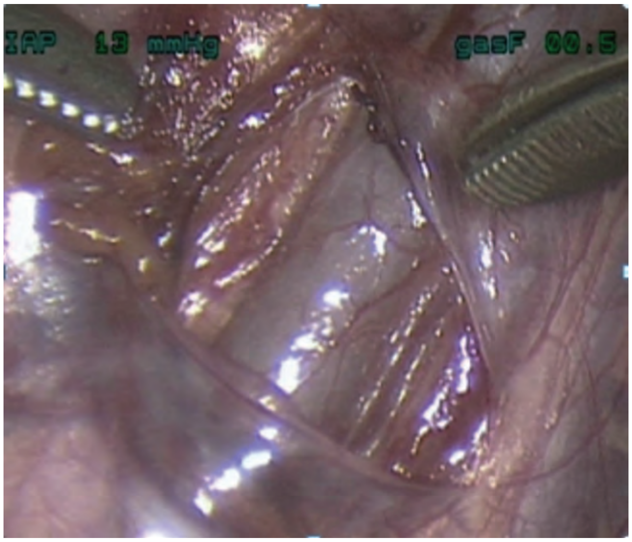

Figure 80.5 Large vein, anterolateral.

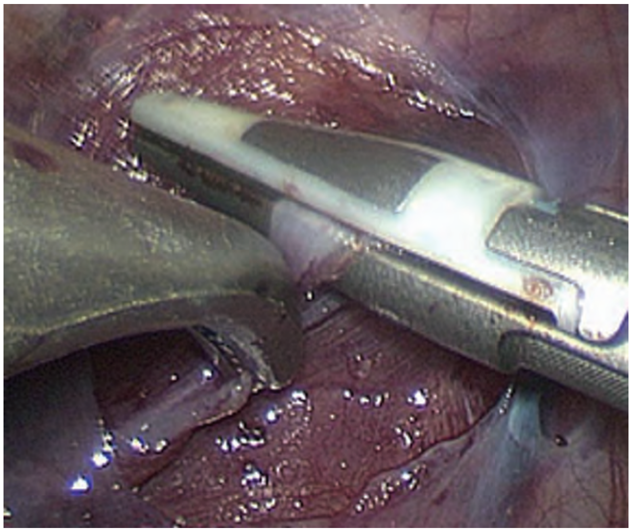

Figure 80.6 LigaSure™ device used to ligate and divide the vein.

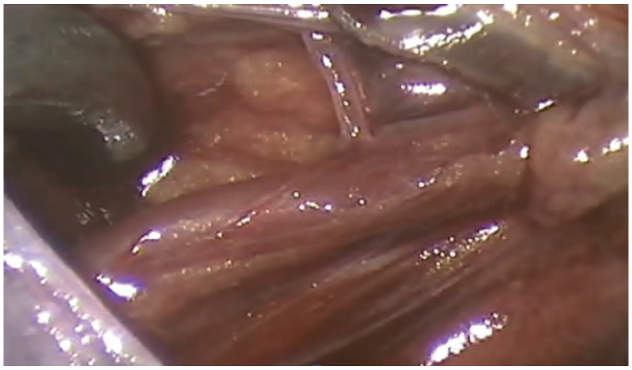

Figure 80.7 Spermatic artery.

ligated using the LigaSure device. The use of fulguration tends to spread to the fine lymphatics. The use of a laparoscopic Doppler may be helpful in identifying the artery (Figure 80.7). Often, the artery will not have a strong pulsation after manipulation. The Doppler probe can be used to help with the dissection as well (Figure 80.8). Under the superb magnification of the laparoscope, the lymphatic vessels can be identified as small, translucent vessels (Figure 80.9). These can be teased away from the vein bundles using two endoscopic dissectors.

The patient is returned to the supine position and evaluated for hemostasis. Any blood or irrigant that may have collected can be aspirated using the aspirator–irrigator. However, in most cases, this is not needed and therefore need not be routinely opened on the field.

Laparoscopic exit/port removal is performed under the direct vision of the laparoscope. Use of 5-mm ports avoids the need for fascial closure; however, we almost always close the supraumbilical and lower midline sites with a single absorbable suture. The patient is observed once more for hemostasis after efflux of pneumoperitoneum. The skin is closed with absorbable suture in a subcuticular fashion and sealed with a skin adhesive.

An alternative to the above trocar positioning is use of the long 5 mm trocar for the supraumbilical laparoscope port. The second 5 mm short trocar placed half to two-thirds of the way between the umbilicus and pubic symphysis in the midline is equipped with a toilet seat type 3 mm reducer cap to allow for use of smaller 3 mm instruments (Maryland dissector and endoshears) in addition to the 5 mm LigaSure device. The third port can be substituted with a 3 mm port placed lateral to the epigastric vessels on the side ipsilateral to the varicocele as above but instead of in line with the umbilicus, it should be approximately midway between the two midline ports. This is necessary to allow for the shorter 3 mm instruments to be within working distance of the surgical site.

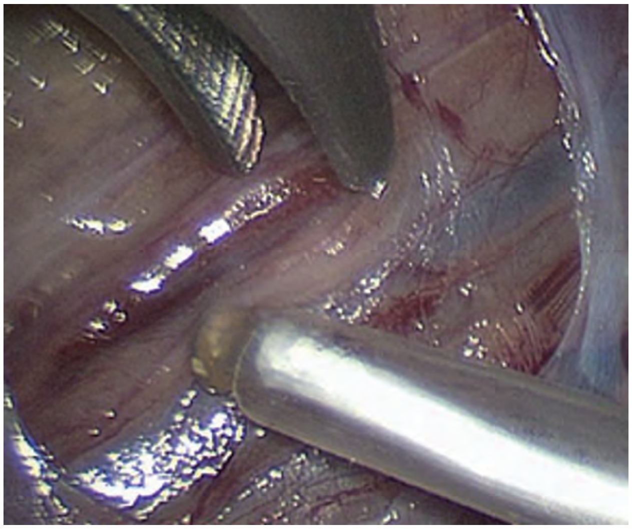

Figure 80.8 Doppler probe used for dissection and identification of the spermatic artery.

Complications

The main complications associated with laparoscopic varicocelectomy are postoperative hydrocele and varicocele recurrence (or perhaps, more accurately, persistence). The incidence of these two complications depends on whether the approach taken is artery sparing or non-artery sparing, and lymphatic sparing or *en masse* ligation. Other potential complications include bleeding, either from trocar placement (e.g. inferior epigastric vessel injury) or from the spermatic vessels. The use of the LigaSure device has significantly decreased the likelihood of inadequate ligation of these vessels and to date, we have not had any problems with delayed

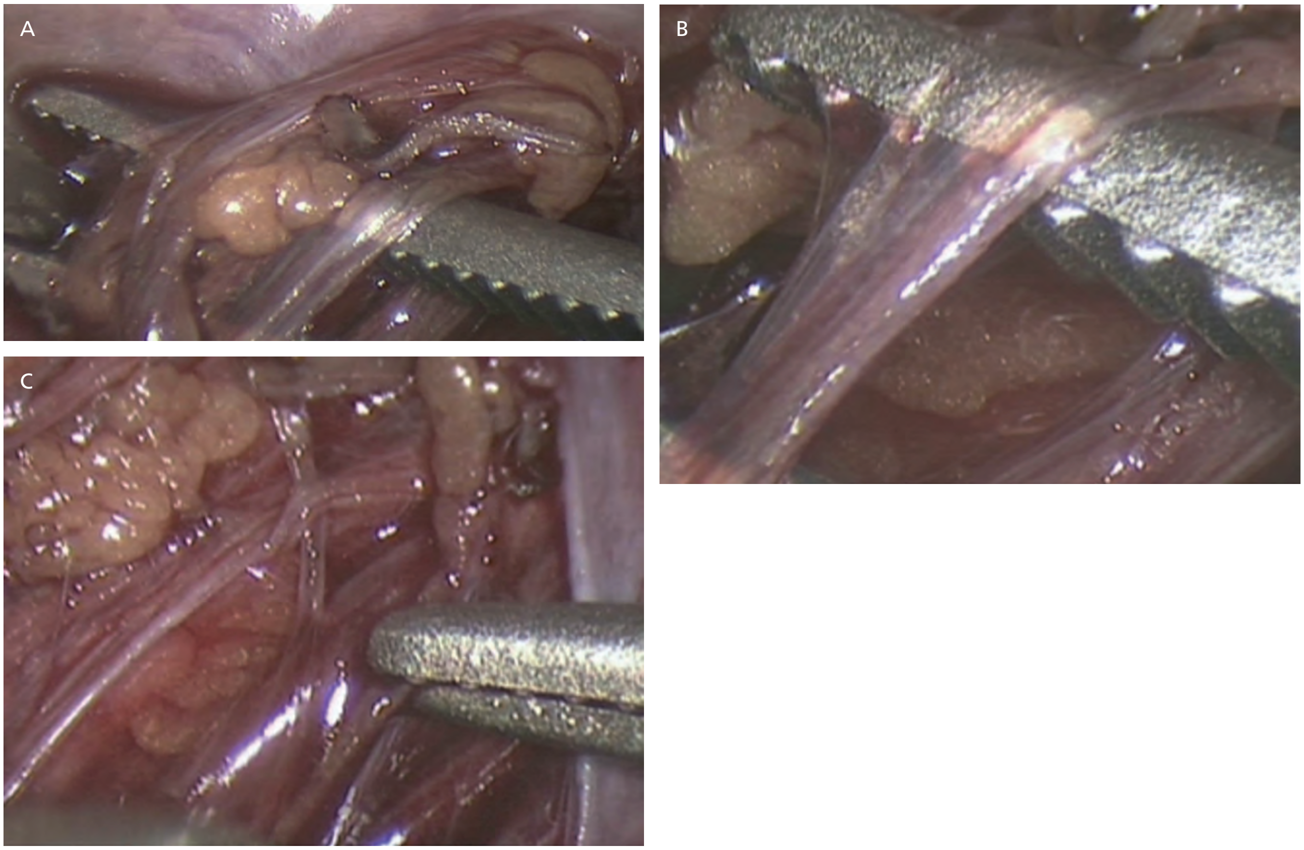

Figure 80.9 (A–C) Lymphatics as seen under magnification.

bleeding. Slight Trendelenburg allows gravity to retract the bowel away from the surgical field, possibly reducing the risk of injury from the surgical instruments.

Results

The true tests of success for varicocelectomy, regardless of approach or technique, are hydrocele formation and recurrence/persistence of varicocele. Initial reports have given variable results and have called into question the validity of using laparoscopy for the correction of varicoceles. However, there is evidence to suggest fewer wound complications, decreased testicular/scrotal edema, shorter operative time, and decreased need for postoperative analgesia using the laparoscopic approach. Podkamenev *et al*. randomized 654 patients to laparoscopic (434 patients) versus open varicocelectomy (220 patients), with both techniques using the Palomo technique of *en masse* ligation of the artery and vein above the internal inguinal ring with lymphatic preservation [31]., The groups were controlled for age, and varicocele side and grade (2–3). No statistical difference was found with regards to recurrence and hydrocele formation (<2%), but the differences in the following parameters were statistically significant: decreased genital edema, decreased length of stay (3 days for the laparoscopic group vs 7 days for the open group), decreased operating time (15 min vs 26 min), and decreased need for postoperative analgesia (14% vs 23%). McManus *et al*. evaluated 72 patients randomized to laparoscopic varicocelectomy (36 patients) and subinguinal microscopic varicocelectomy (36 patients). They showed a statistically significant difference in mean operative time (34 min for the laparoscopic group vs 60 min for the subinguinal microscopic group), hydrocele formation (8% vs 0%), and recurrence (0% vs 11%) [19]. Despite the 8% hydrocele formation rate, ultimately, only 2.7% required hydrocelectomy. Both these studies were limited by their relatively short follow-up time of approximately 6 months. We have noted that hydroceles and recurrences can sometimes present more than 1 year after repair.

Hydrocele (Table 80.2)

As discussed above, there is a high incidence of hydrocele formation (7–30%) with the Palomo technique [14, 18, 22, 23, 32], although a much smaller percentage actually require repair [14]. A decrease in incidence of hydrocele formation appears to correlate with sparing of the lymphatics, either with the microsurgical or laparoscopic technique, presumably because of the increased magnification and hence increased accuracy of identification with these techniques [17, 18] This explains why the *en masse* ligation associated with the Palomo technique renders such high rates of postoperative hydrocele. The rate of hydrocele formation in conventional (non-microsurgical) varicocelectomy has ranged from 3% to 14% [23, 33–35], whereas with the microsurgical approach multiple series have reported no occurrences [19, 33, 34, 36, 37]. Percutaneous procedures, which select for veins and not lymphatics, are not associated with hydrocele formation [38, 39].

Initial results of laparoscopic varicocelectomy showed the same problem as with conventional, i.e. non-microsurgical, open varicocelectomy and the Palomo method with respect to hydrocele formation, rates of which ranged from 11% to 20% [17, 24, 34, 40]. This can be explained by the fact that initial reports did not make use of the technologic advantage of laparoscopy and its role in preservation of the lymphatics [22, 40]. Our adoption of the lymphatic-sparing modification has given favorable results, with a decrease in the incidence of hydrocele formation from 11.4% to 3.4%, but no significant effect on the persistence or recurrence of varicocele [17]. A reduction in rate of hydrocele formation

Table 80.2 Rates of hydrocele formation and recurrence for different techniques.

Technique	Lymphsparing	Artery sparing	Hydrocele (%)	Recurrence (%)
Retroperitoneal/Palomo	No	–	7–30	0–4
Modified Palomo	Yes	–	0	2
Conventional Inguinal/Subinguinal	No	Yes		14
	No	No	3–14	13–14
Microsurgical	Yes	Yes	0	0–11
Laparoscopic	Yes	Yes	3	7–25
	Yes	No	1–4	0
	No	Yes	12	18
	No	No	11–20	0–9
Radiographic	Yes	Yes	0	5–22

from 17.9% to 1.9% has also been observed at another institution [24].

Recurrence (Table 80.2)

Feber and Kass reported on their 20-year experience with 312 patients who underwent the open Palomo procedure with a recurrence rate of 3.9% [14]. Others have reported similarly low rates of recurrence with the traditional and modified Palomo techniques [18, 23]. This is related to the nature of the Palomo technique wherein the artery is not spared, resulting in ligation of the veins that are intimately associated with the spermatic artery, as mentioned above [15]. Conventional inguinal/subinguinal approaches have had recurrence rates around 14% regardless of whether the artery was spared or not [18, 23, 34]. For the microsurgical approach, recurrence rates have ranged from 0% to 11% [19, 34, 37].

Low recurrence rates with sacrifice of the artery have also been seen with the laparoscopic approach. A recurrence rate of 7–25% was demonstrated with laparoscopic sparing of the artery, a rate that is intolerably high [24, 37, 40, 41]. However, in one series in which the laparoscopic surgery sacrificed the artery, the recurrence rate plummeted from 25% to 0% [41].

Finally, for the percutaneous/radiographic modality, May *et al*. reported superiority of laparoscopic varicocelectomy over antegrade sclerotherapy with regards to recurrence (4.9% vs 15.7%) with median follow-up of 59 months [39]. Another study found a recurrence rate as high as 22% for antegrade sclerotherapy [38]. Microcoil embolization appears to give a lower rate of recurrence (4.8%) [42].

Follow-up

Typically, we see our adolescent patients at 2 weeks, 6, 12, and 24 months following repair. We follow them by palpation and Doppler ultrasound, evaluating both peak retrograde flow and maximum vein diameter. We believe that any patient with some degree of residual venous backflow or dilation should be followed for longer than 2 years. In patients in whom the varicocelectomy was performed for infertility, follow-up should be longer.

Conclusions

Strict conclusions are difficult to draw based on the available literature due to the variability of technique, even when the approach, whether open, laparoscopic, or radiographic/percutaneous, is the same. As is the case with all evolving techniques, many series do not clearly indicate whether the artery or lymphatics is spared, making it difficult to interpret results regarding hydrocele formation or varicocele recurrence. The results discussed above were synthesized from the few articles that do remark on these specific details of the surgery. Even then, these results are mainly from case series and not randomized controlled studies. Moreover, the follow-up periods were widely variable. While some trends can be determined, further study is required.

Hydrocele formation appears to be dependent on whether the lymphatics are spared or not. Naturally, in order to spare the lymphatic channels, magnification either by the microscope or laparoscopy is necessary. The less than 5% rate of hydrocele formation in laparoscopy with lymphatic sparing is much better than the rates reported for Palomo and conventional varicocelectomy. However, it must be kept in mind that not all of these hydroceles require intervention. Laparoscopy does lose out to the 0% hydrocele formation rate with microsurgical and radiographic modalities, although this must be balanced against the almost doubled operative time in most hands for microsurgery and the high recurrence rate and specialization of the radiographic route.

Recurrence appears to be dependent on whether or not the artery is spared. Sacrificing the artery decreases the rate of recurrence significantly, and is precisely why the Palomo technique and its variations have such a low recurrence rate. However, sacrificing the artery laparoscopically can afford similarly low recurrence rates, while at the same time preserving the lymphatics, thereby keeping the hydrocele rate low, a goal the traditional Palomo technique has a problem achieving.

In conclusion, the optimum of low rates of hydrocele formation and of recurrence can be achieved with the microsurgical or laparoscopic routes. Laparoscopic varicocelectomy with sacrificing of the artery and preservation of the lymphatics can give results that are just as good, if not better, than microsurgical varicocelectomy, and is a viable option for patients with varicoceles.

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CHAPTER 81

Renal Surgery for Benign Disease

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Introduction

Benign renal disease processes represent an ideal application for the laparoscopic approach due to the significant morbidity associated with the large flank or subcostal incisions required for the corresponding open procedures. Improvements in the understanding of laparoscopic anatomy, instrumentation, and laparoscopic training have made many of these operations commonplace at both community and university centers. We outline the major procedures now being performed for benign renal diseases and provide a step-by-step guide for approaching these operations that we hope will prove useful for both experienced and inexperienced laparoscopic surgeons.

Indications

Simple nephrectomy

Laparoscopic simple nephrectomy is often far from "simple" even for the most experienced laparoscopic surgeon, because the conditions for which it is performed often result in significant perinephric scarring. The end result of these conditions is typically a kidney with marginal function and associated pain, hematuria, recurrent infections, or renovascular hypertension. Initiating conditions include chronic obstruction from an undiagnosed or inadequately treated ureteropelvic junction obstruction (UPJO), stone disease, extrinsic compression, or iatrogenic strictures of the ureter [1, 2]. Patients with persistent infections in poorly functioning kidneys from vesicoureteral reflux (VUR) or associated stone disease may require a nephrectomy to halt recurrence of the infectious process or pain associated with the condition. Similar symptoms may occur in patients with acquired renal cystic disease, autosomal dominant polycystic kidney disease (ADPKD), or multicystic dysplastic kidneys, ultimately necessitating removal. Atherosclerosis, fibromuscular abnormalities, or prior trauma to the renovascular system can result in a poorly functioning renal unit associated with renin-mediated hypertension not alleviated by medical management. This condition requires surgical removal of the affected side in order to control blood pressure. A large angiomyolipoma not amenable to a partial nephrectomy would be another condition for which laparoscopic simple nephrectomy could be considered. Xanthogranulomatous pyelonephritis (Figure 81.1) and renal tuberculosis are two infectious conditions of the kidney that are relative contraindications to laparoscopic removal, as will be discussed later.

Heminephrectomy

Laparoscopic removal of an upper or lower pole moiety is performed for certain benign disease processes in kidneys with a complete duplication of the collecting system. Upper pole obstruction and a differential decline in function most commonly occur in association with an ectopic ureter, with or without associated reflux, or an obstructing ureterocele [3, 4]. Isolated loss of lower pole

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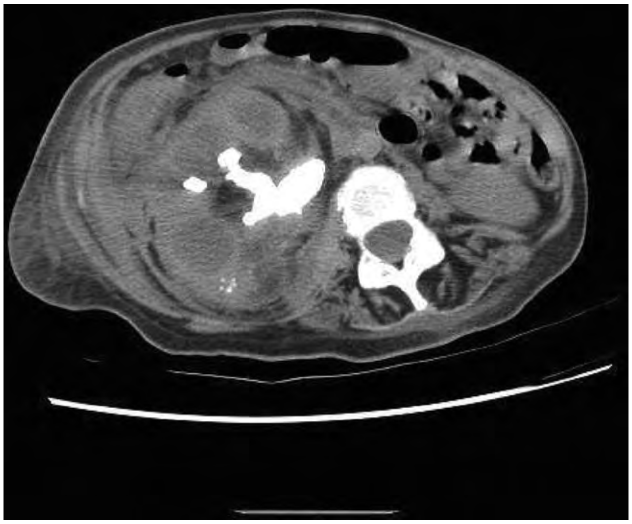

Figure 81.1 Abdominal-pelvic CT scan demonstrating the classic "bear-paw" appearance of a patient with xanthogranulomatous pyelonephritis of the right kidney. Note the presence of renal calcifications along with replacement of the collecting system, with a fatty soft tissue mass representing lipid-laden macrophages. Although perinephric stranding is visible, the intensity of the adhesion formation is not readily apparent as open removal of this kidney required resection of a portion of the liver and mass clamping and oversewing of the hilar structures.

function in the setting of a complete duplication of the collecting system most often is the result of a chronic UPJO or reflux nephropathy [4, 5]. Presenting symptoms include flank pain, recurrent infections, incontinence, or more subtle signs of chronic infection [4]. In such cases, the amount of residual function in the remaining moiety of the affected side justifies whether preservation or removal of that portion of the renal unit should be performed. In cases of reflux or ectopia with obstruction, the associated ureteral segment is also removed as low down as possible to prevent it from serving as a potential reservoir for infection.

Benign cyst disease

The primary indications for decortication of a renal cyst or cysts include pain, hematuria, collecting system obstruction, or associated bowel or respiratory complaints [6–8]. There are four categories of cysts that have been treated laparoscopically with regularity: simple, complex, peripelvic, or cysts associated with ADPKD.

Simple cysts

A possible cause-and-effect relationship between a large simple renal cyst and one of the presenting symptoms noted above is usually established by first performing a percutaneous puncture under ultrasound or computed tomographic (CT) guidance with aspiration of the cyst. If the symptoms improve following the aspiration, then a causal relationship is implied. Unfortunately, puncture and aspiration alone is often inadequate to prevent reaccumulation of the cyst fluid with recurrence of symptoms (Figure 81.2). Instillation of sclerosing agents such as alcohol, providone–iodine, tetracycline, and minocycline increases the overall success rate of percutaneous management to 75–97% [9–13]. Despite the high reported success rate of this minimally invasive procedure, laparoscopic decortication of such cysts is often required as a salvage procedure if symptomatic reaccumulation occurs following percutaneous drainage and sclerosis [7].

Complex renal cysts

Bosniak *et al.* provided diagnostic groupings of cysts based on radiographic findings on enhanced and unenhanced CT scan imaging, which could be used to predict the risk of cystic renal malignancy (Table 81.1) [14]. The incidence of malignancy in Bosniak I lesions is negligible and the high risk of cystic renal cancer in Bosniak IV lesions (90%) requires that they are approached as if they are malignant. The use of laparoscopy for treating Bosniak I and IV lesions therefore is not controversial. There is controversy regarding whether or not laparoscopy should be utilized for the diagnostic evaluation and treatment of symptomatic Bosniak II and III lesions given their risk of malignancy. Obvious concerns exist regarding the possibility of tumor spillage should a lesion prove to be a cystic renal cancer, especially when a transperitoneal approach is utilized. Catastrophic cases of diffuse tumor seeding following transperitoneal laparoscopic decortication have been described [16]. Attempts to define the presence of malignancy via pre-decortication cyst aspiration cytology have a reported false-negative predictive value of 20% [6]. Traditionally, the safest approach to these lesions has been an open excision, treating the lesions as if they were a malignancy; however, several series have suggested the potential utility of the laparoscopic approach [7, 17].

Peripelvic cysts

Approximately 6% of all simple renal parenchymal cysts can be found immediately adjacent to or abutting the renal pelvis [18]. Although it is not clear what percentage will become symptomatic, cysts located in these areas can result in obstruction of the collecting system with resultant calyceal distention, pain, hematuria, recurrent infections, and stone formation [19–21]. Percutaneous aspiration and marsupialization as well as retrograde ureteroscopic treatment of these cysts have

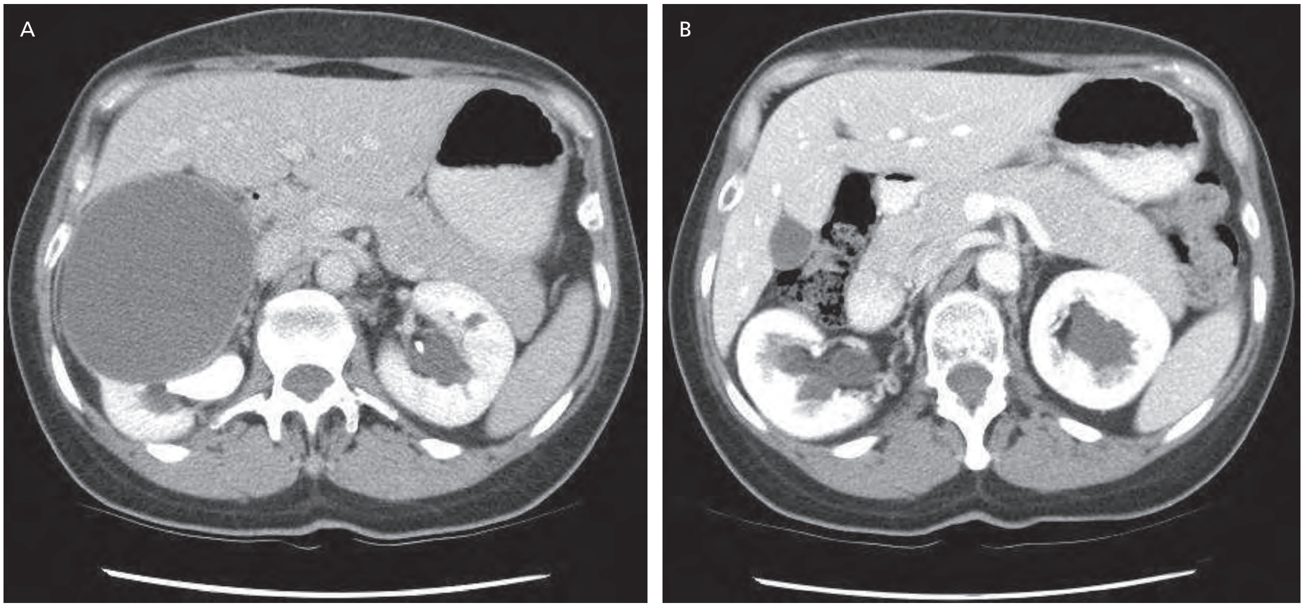

Figure 81.2 Abdominal–pelvic CT scan revealing reaccumulation of a large symptomatic simple cyst of the right kidney, which failed two prior percutaneous aspiration attempts, the last involving sclerosis with alcohol. (A) Note the intimate association and extension of the cyst beneath the inferior edge of the liver. (B) This patient eventually underwent successful laparoscopic cyst decortication.

Table 81.1 Bosniak criteria* [6, 14, 15].

Type	Wall	Septa	Calcification	Enhancement	Malignant Potential
I	Thin	Absent	Absent	Absent	<0.7%
II	Thin	Few	Few	Absent	24%
III	Slightly thickened	Multiple	Multiple	Absent	41%
IV	Thickened	Multiple with nodularity	Extensive with nodularity	Present	90%

*Determined by CT imaging with and without contrast.

been employed with variable success [7, 22, 23]. The use of sclerosing agents in this scenario is risky due to the close proximity of the collecting system and the potential for injury [24, 25]. Due to their location, laparoscopic decortication of these lesions is associated with an increased risk of collecting system injury relative to simple cyst excision [7, 20] and often requires additional operative maneuvers to prevent such occurrences.

Cysts associated with autosomal dominant polycystic kidney disease

Unilateral and bilateral decortications of multiple cysts associated with ADPKD have been shown to improve flank and abdominal pain and, in some cases, associated gastrointestinal and diaphragmatic complaints in these patients [8]. As many as 60% of patients with ADPKD will suffer from chronic flank pain, which is largely thought to be a result of capsular distention providing noxious stimulus of visceral afferent nerves to the kidney [26, 27]. Other potential causes of painful stimulus include episodes of cyst infection, as well as acute hemorrhage [28]. Compression of normal surrounding areas of renal parenchyma has also been hypothesized to create ischemia within the affected kidneys, leading to activation of the renin–angiotensin system with resultant hypertension and progressive decline of renal function over time [28, 29].

Percutaneous aspiration of these cysts often leads to rapid reaccumulation and recurrence of pain. Aggressive open decortications have resulted in more durable pain relief in 80–90% of patients at 1 year; however, progressive recurrence over time has been reported as new cysts form and others enlarge [30, 31]. Ye *et al.* reported initial pain relief in 92% of their patients at 1 year, but this declined to 81% by 5 years [31]. Unfortunately, open decortications were also associated with significant morbidity and even mortalities, with several published series in the late 1950s reporting mortality rates of 11% [32, 33]. A more contemporary series by Fleming *et al.*

described one death among28 patients who underwent open decortications, while 13% suffered prolonged ileus and 10% cardiac dysrhythmias [34]. In 1995, Teichman *et al.* reported the successful use of laparoscopy to perform cyst decortications in six patients with ADPKD [35]. Lee *et al.* more recently reported durable pain relief in ADPKD patients 3 years following laparoscopic decortication, with additional improvements in blood pressure, quality of life, and stabilization of renal function during the study period [8].

Calycealectomy

Calyceal diverticula are transitional cell-lined, dilated chambers that connect with the collecting system via a narrow opening. Their etiology is unclear, but the leading theories include a failure of fusion of one of the branchings of the ampulla of the ureteric bud [36, 37] versus rupture into the collecting system of an adjacent abscess [38]. Approximately 40% have associated calculi [36, 37]. Patients with this condition often present with pain, infections or hematuria [38]. Occasionally, diverticula are asymptomatic and discovered incidentally on imaging procedures performed for other reasons. These may not require surgery, depending upon their size, patient age, comorbidities, and preference. Stone clearance success rates for percutaneous approaches to a stone-bearing diverticulum have been reported to be as high as 70–95%, but 20–33% may have persistence of the diverticulum [39–43]. This technique can be extremely challenging in patients with anteriorly located lesions due to the difficulty of accessing the diverticulum without passing tangentially through a significant portion of the renal parenchyma.

Alternative treatment approaches include shockwave lithotripsy (SWL) and a retrograde ureteroscopic approach. SWL has a low stone clearance rate of 6–58% [39, 40, 44–47], but a surprisingly high percentage of symptomatic patients (75%) have reported resolution of their symptoms with this technique [45]. If the diverticulum can be accessed from below utilizing a ureteroscope, an alternative approach is to incise or balloon dilate the neck of the diverticulum, and to then attempt to ablate the diverticulum with laser energy or electrocautery. This technique can be cumbersome for large stone burdens and often the neck of the diverticulum cannot be readily identified. In addition, adequate collapse and ablation of the diverticulum often does not occur. Pang *et al.* described a successful stone clearance rate of 66% using this approach [48].

The laparoscopic approach to calyceal diverticula was first described in 1993 [38] and has proven to be ideally suited for anterior- or lateral-based diverticula with associated large stone burden and minimal overlying parenchyma. This approach can also be applied to posterior-based lesions, but is arguably more invasive than the percutaneous approach.

Nephropexy

The condition of nephroptosis (pathologic hypermobility of the kidney) typically presents as intermittent pain in the flank or lower quadrant with standing activities that improves when supine. This condition can also be associated with hematuria, upper or lower tract urinary infections, urinary calculi, or hypertension [49–53]. Classically, it occurs in the right kidney of thin women or patients who have recently experienced a significant weight loss [54], with some series reporting as high as a 10:1 female predominance [55].

Laparoscopic fixation of the kidney to the retroperitoneal fascia (nephropexy) is performed to prevent rotation and/or descent of the kidney to alleviate episodes of pain-inducing obstruction or ischemia. Downward displacement is thought to cause stretching and partial luminal narrowing of the main renal artery, which has been supported by nuclear renal scan and angiographic findings [51, 56, 57]. Previously, nephroptosis was felt to warrant surgery if radiographic descent of the kidney by more than two vertebral spaces (5 cm) on standing relative to supine images was demonstrated [54, 58, 59]. The historic lack of clinical improvement in patients operated on using this diagnostic criterion has lead to a more functional stratification of surgical candidates [54]. Patients with the greatest likelihood of benefiting from a nephropexy have now been defined as symptomatic individuals with documented obstruction [prolonged one-half excretion times ($t_{1/2}$), decreased relative function, and/or renal ischemia (poor 1–2 min perfusion times) on a diuretic renal scan on the affected side that improve on the supine relative to the upright study (Figure 81.3) [54, 59]. Fornara defined the minimum requirements prior to performing a nephropexy as a symptomatic patient with a documented functional difference of at least 10% between the supine and sitting nuclear renal scans [59].

Patient preparation

Patient preparation should include a complete history and physical examination with specific attention to prior transperitoneal or retroperitoneal surgical procedures, episodes of associated peritonitis, locations of abdominal scarring, and other conditions, which could add complexity to a laparoscopic approach [60]. Conditions resulting in hepato- or spleno-megaly such as fatty liver infiltration or portal vein hypertension can also complicate laparoscopic operations on retroperitoneal structures, respectively. Prior lumbar fixations, kyphoscoliosis, or a depressed flattened diaphragm associated

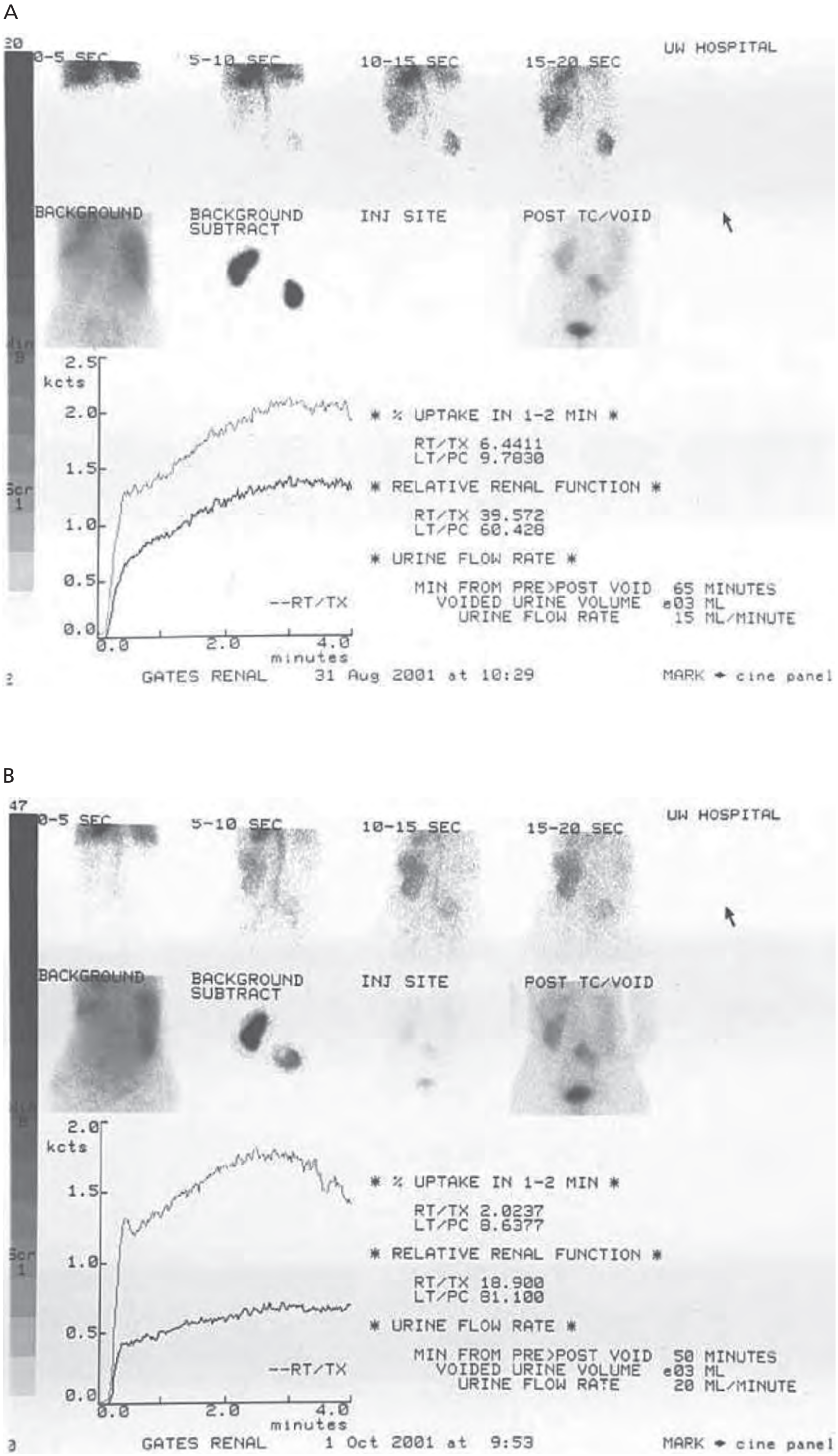
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Figure 81.3 Diagnostic nuclear renal lasix scans of a patient with clinical nephroptosis. (A) Preoperative supine study reveals reasonable perfusion (1–2 min uptake: right 6.4%; left 9.8%) and relative function (right 39.6%; left 60.4%). (B) Preoperative sitting study demonstrates classic declines of perfusion (1–2 min uptake: right 2.0%; left 8.6%) and relative function of the ptotic right kidney (right 19%; left 81%). Note the low-lying position of the right kidney on the sitting relative to the supine images. (C) Post-laparoscopic nephropexy, sitting study demonstrates corrected position of the right kidney and marked improvements in perfusion (1–2 min uptake: right 11.0%; left 8.8%) and relative function (right 55%; left 45%).

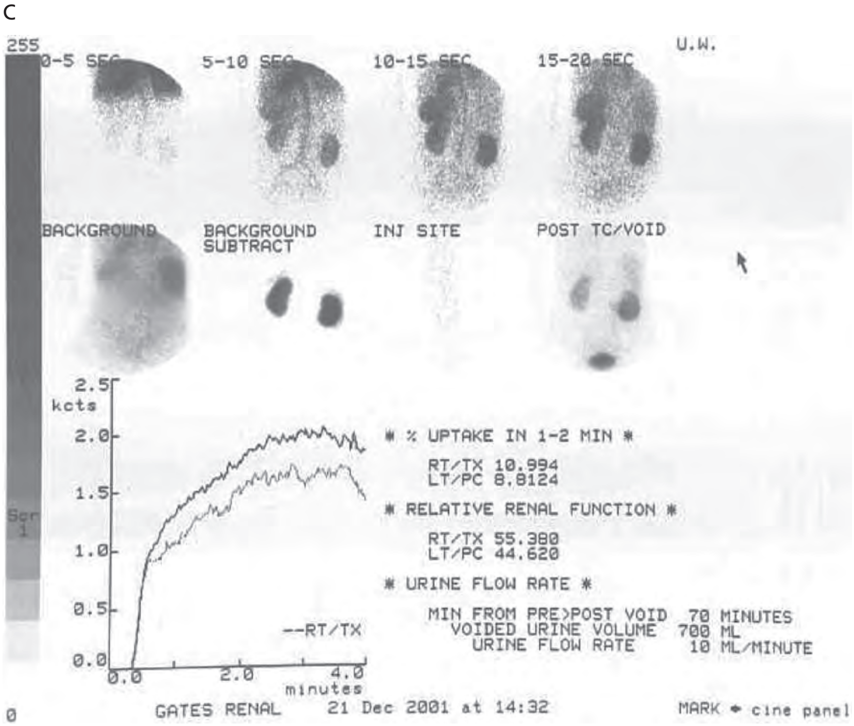
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Figure 81.3 *Continued*

with severe cases of chronic obstructive pulmonary disease can also impact the positioning and exposure required for laparoscopic operations. Laparoscopic surgery in the morbidly obese patient, although previously thought to be a relative contraindication [61], has subsequently been shown to be efficacious and to yield results superior to open surgery [62]. This condition does, however, require minor modifications in port placement due to the thickness and mobility of the large abdominal pannus.

Appropriate imaging studies to assist in surgical planning and patient selection should be performed. Our preferred study for patients undergoing laparoscopic simple nephrectomy is a CT scan with and without contrast, which is extremely helpful in outlining the anatomy of the kidney and its surrounding organs. In patients with atherosclerotic disease, careful attention should be given to the artery of the affected renal unit to make sure there is no calcified plaque that can result in clip or staple fracturing and uncontrolled hemorrhage during laparoscopic attempts at securing the vessel [63]. In patients with renal cystic disease, delayed contrast sequences delineating separation between the collecting system and the cyst wall are particularly helpful, especially in cases of ADPKD in whom multiple cysts are decorticated. These delayed images define the relationship of renal pathology to the collecting system and help determine whether or not preoperative ureteral catheter placement is indicated. A plain film prior to and at the end of acquiring the delayed images can also be used to provide coronal imaging of the collecting system when evaluating such nuances as whether or not a stone is located within a diverticulum. Alternative modalities to image patients with a contrast allergy or reduced overall renal function include a noncontrast CT scan or magnetic resonance imaging (MRI) with and without gadolinium administration.

Nuclear renal scan imaging to document poor function in the affected side or moiety prior to nephrectomy or heminephrectomy, respectively, is often performed in addition to the above noted studies. This is a critical imaging study for patients with a duplicated system in whom a potential heminephrectomy is planned. Patients with suspected renin-mediated hypertension can be evaluated using provocative captopril nuclear renal scan imaging or renal vein renin samplings with ultimate "gold standard" confirmation provided by angiography [64]. In patients with radiographically confirmed nephroptosis, the essential diagnostic study is the nuclear renal scan performed in both a supine and sitting position. The initial study often performed in these patients is a stone protocol CT or CT urogram, as the symptoms are difficult to differentiate from an intermittently obstructing calculus or UPJO. The supine and sitting nuclear renal scans need to be performed on two different dates and comparisons made between the 1–2 min perfusion times, relative renal function, and $t_{1/2}$ excretion times. A reduction in the perfusion or prolongation of the drainage times in the sitting position, in addition to symptomatic changes and demonstrated descent of greater than two vertebral bodies (5 cm) on urogram imaging are diagnostic (Figure 81.3) [54, 59].

Laboratory and additional patient performance assessments are identical to those used for open operations. These should include routine hematologic, chemistry, and coagulation studies, as well as a dipstick and microscopic urine assessment. Patients with atherosclerotic renovascular disease should undergo careful cardiovascular assessment as concomitant carotid and coronary artery disease is often present and may need correction prior to nephrectomy.

We typically perform a type and screen for blood products. Rarely, when more significant bleeding is anticipated, a type and cross or autologous blood donation should be considered. This latter approach may also be applied to all patients early in an individual surgeon's laparoscopic experience. Patients are instructed to avoid the use of Aspirin for 1 week and all nonsteroidal anti-inflammatory medications for 72 h prior to surgery. If the patient is on oral anticoagulant therapy, this should be discontinued at least 5 days prior to surgery if feasible, or the patient converted to short-acting subcutaneous or intravenous agents when the duration off anticoagulation must be minimized.

A mechanical bowel preparation consisting of a clear liquid diet the day prior to surgery and administration of a bottle of magnesium citrate is utilized for all laparoscopic procedures. Cleansing of the bowel is important as it decompresses the large bowel, aiding in visualization and facilitating dissection. In addition, it also limits fecal soiling should a bowel injury occur, and anecdotally appears to speed recovery of bowel function.

Informed consent

Every procedure that is scheduled to be performed laparoscopically should include the phrase "laparoscopic, possible open" on the surgical posting and consent form. It should also be thoroughly explained to the patient that if it becomes unsafe or deemed impossible to progress laparoscopically, then the procedure will be converted to an open operation. Although a complication such as a bowel injury or uncontrolled hemorrhage can lead to an open conversion of a laparoscopic case, conversion in and of itself should not be viewed by the patient as a complication, but rather a safe alternative for completion of the proposed procedure. Similar to open operations, informed consent for laparoscopic surgical procedures should include a specific discussion of all potential major and minor complications. It should also include an accurate revelation of the individual surgeon's experience with laparoscopy and the particular surgical procedure being performed. If the surgeon will have a proctor or more experienced laparoscopic surgeon assisting them, this should also be clearly discussed, including that individual's qualifications. Utilization of specialized equipment that is new to the operating surgeon, such as robotics, which could significantly alter the flow or outcome of the operation, should also be revealed. Table 81.2 lists the elements that should be included within the informed consent for all laparoscopic renal procedures, including several additions specific for heminephrectomy, renal cyst ablation, calycealectomy, and nephropexy.

Table 81.2 Risk elements of the informed consent for all laparoscopic renal procedures.

Bleeding requiring transfusion
Infection (retroperitoneal or superficial)
Injury to adjacent structures (e.g. bowel, adrenal, spleen, liver, pancreas, etc.)
Renal insufficiency
Thromboembolism
Cardiovascular event
Postoperative bowel obstruction or prolonged ileus
Neuromuscular injury
Hernia formation
Persistent pain
Additional risk elements
Heminephrectomy • Persistent urinary leakage: need for additional drainage procedure (e.g. stent or percutaneous drainage)
Renal cyst ablation • Injury to the collecting system • Persistent urinary leakage: need for additional drainage procedure (e.g. stent or percutaneous drainage) • Cyst recurrence
Calycealectomy • Injury to the collecting system • Persistent urinary leakage: need for additional drainage procedure (e.g. stent or percutaneous drainage) • Stone extrusion • Calyceal or stone recurrence • Persistent pain
Nephropexy • Continued hypermobility

Preoperative preparation

On call to the operating room, a broad-spectrum parenteral antibiotic (second-generation cephalosporin) is usually administered. The pneumoperitoneum has been shown to reduce venous velocity and blood return from the lower extremities [65]. To improve the mechanical return of blood from the lower extremities and to stimulate the release of plasminogen activators [66], Ted Hose and sequential compression devices are applied to the lower extremities in all patients undergoing prolonged laparoscopic procedures.

The operating table should be equipped with a kidney rest and push button electric controls allowing for flexion, air-planing, and Trendelenburg positioning. We utilize 3-inch foam padding on the entire surface of the operating table to limit pressure points during the operation. Obese patients with a large abdominal pannus may also require the use of a beanbag to assist in low pressure, contoured securing of all aspects of their excess girth. In cases where the beanbag is utilized, a large gel pad can be placed over its surface and supplemented using additional foam.

Patient positioning: transperitoneal procedures

After the endotracheal tube has been secured, the patient is placed with their down kidney directly over the kidney rest in the flank position, with slight (15º) posterior tilt from the vertical. This degree of angulation improves access to the surface of the abdomen for port placement and lessens medial rotation of the kidney as dissection progresses. Some surgeons prefer vertical flank positioning and then adjust the position by actively air–planing the table at the beginning of the case to assist in port placement, or during the case when medial rotation of the kidney occurs. A posterior gel-pad roll covered by a towel can be positioned lengthwise across the patient's lower back and secured to the table using a double-jointed support arm to provide reliable stabilization of the patient even during full air-planing away from the operating surgeon. The patient's lower leg is flexed and the upper leg is kept straight as ample pillows are placed between the legs to keep them at a comfortable neutral separation without abduction. Pillows should be placed perpendicular to the lower extremities to limit the possibility of the lower leg rolling off the operating table as it is air-planed. Care must be taken to minimize the amount of pillow ends protruding from between the upper thighs as these can inhibit the downward excursion of instrument's inserted through lower quadrant ports. Foam should be utilized to pad the tubing of the sequential compression devices to prevent contact between the body and these firm structures.

We utilize two arm boards placed adjacent to one another on the opposite side of the table from the patient's pathology to support their arms. An axillary roll made from egg-crate foam or gel-pad material is inserted two finger-breadths beneath the axilla to prevent excessive stretch of the brachial plexus while minimizing contact pressure. The kidney rest is elevated slightly and the table is flexed minimally to increase the working space between the lower rib cage and the iliac crest, thus facilitating separation of trocars on the abdomen or flank. Excessive kidney rest elevation and flexion of the table is discouraged as it can actually reduce the working space within the abdomen and may lead to neuromuscular injury to the flank in contact with the operating table [67]. A sufficient number of pillows should be placed between the arms to allow comfortable shoulder width separation. These pillows are oriented in line with the arms and are inserted deep into the axilla of the upper arm; otherwise they will take up too much space along the abdomen and limit upward movements of the laparoscopic instruments.

A strap is placed across the lower legs of the patient in the area of the mid calf and the electrocautery pad is adhered to the upper thigh. Two towels are folded lengthwise and one is placed at the hip just above the cautery pad and extending downward to cover the genitalia, while the other passes from the elbow to across the shoulder of the upper arm. Two to three passes of 3-inch cloth tape are brought from table edge to table edge across the towels, with care taken not to place too much compressive force at the point of body contact. After the tape passes over the shoulder of the upper arm and approaches the elbow, it is split from the far end and wrapped on either side of the tower of pillows on the arm boards (Figure 81.4). This secures the arms, the pillows on which they rest, and the upper torso to the operating table. A foam or gel-pad ring may be required to keep the patient's head in a neutral location after the patient has been positioned. Air-planing and Trendelenburg movements of the table should be tested prior to prepping the abdomen and flank to ensure that all areas of the patient are adequately secured.

When a beanbag is utilized, it is pushed up around the patient's abdomen and back in a cradling fashion with care taken not to elevate the edges so high that they may inhibit downward movements of the laparoscopic instruments. Care must also be exercised to keep the supporting edges broad as suction is being applied to solidify the beanbag; otherwise narrow edges of contact can produce excessive pressure and result in myonecrosis. Two-inch foam strips can be inserted along contact points to provide necessary extra padding.

Bilateral simple nephrectomy is occasionally indicated, with the most common clinical scenario being removal of the native kidneys in kidney transplant recipients due to persistent hypertension, pyelonephritis, vesicoureteral reflux, protein wasting nephropathy, hematuria, or painful cystic disease [68, 69]. In these cases, the operating table is prepared in a similar fashion to that for unilateral cases with the exception that the arm boards are opened on either side at almost 90º to the table. Large foam wedges are placed on each arm board on which the patient's arms rest and are secured

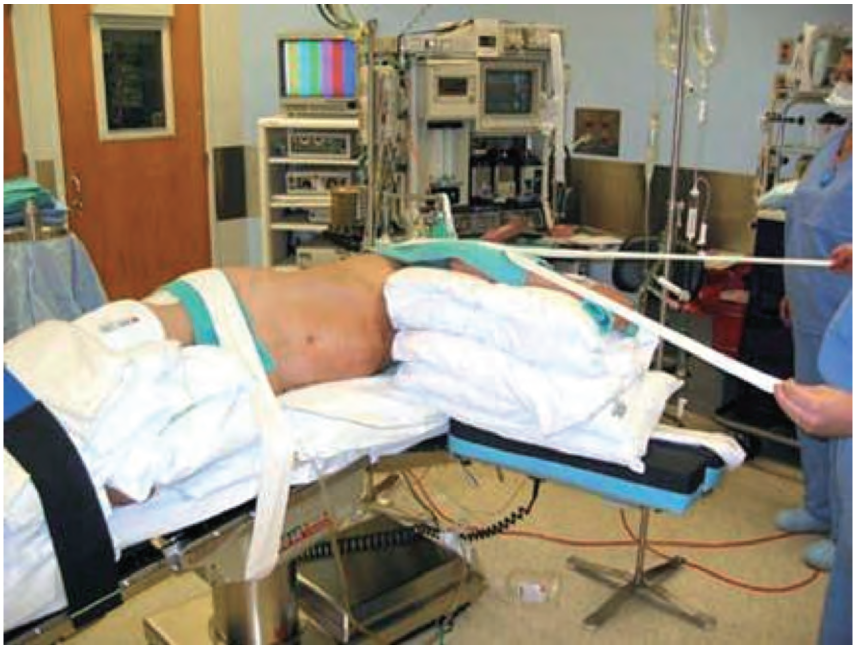

Figure 81.4 Typical patient positioning prior to a right transperitoneal laparoscopic renal procedure. See text for details.

at the forearms. The patient is positioned with their umbilicus at the level of the break in the operating table, the kidney rest is elevated to a neutral position, and the table is flexed slightly. This allows the patient to be fully air-planed to the right or left to elevate the side on which the kidney is being removed, and prevents the need for patient repositioning between nephrectomies [68, 69].

Patient positioning: retroperitoneal procedures

Patient positioning for retroperitoneal procedures is similar to that for transperitoneal operations with several noteworthy exceptions. Since the retroperitoneal space presents a smaller overall working environment and a more limited region of port entry, several maneuvers are critical to optimize both. The patient is placed in a flank position without angulation. This position displaces the lateral peritoneal reflection along with the colon in an anterior direction [70], doubling the undisturbed anteroposterior length of the retroperitoneal space [71]. Chiu *et al.* demonstrated that merely placing a patient in the flank position increased the distance between the quadratus lumborum and the colon by 8.7–27.3 mm on the left and by 4.6–18.1 mm on the right side [72]. The kidney rest is elevated until it is in contact with the flank and more table flexion is utilized than with the transperitoneal approach to enlarge the space between the lower ribs and the iliac wing. This is an important step to enlarge the much more limited surface area for retroperitoneal port insertion. The remainder of the patient padding and positioning is identical to that performed for transperitoneal surgery with the exception that beanbags and posterior gel-pad rolls are not utilized as they can limit the excursion of instruments during retroperitoneal laparoscopic procedures.

Anesthesiology preparations

The anesthesiologists should be encouraged to calculate and replace fluid deficits prior to insufflation of the abdomen to minimize the hemodynamic effects of the pneumoperitoneum that are more pronounced with hypovolemia [73–75]. Nitrous oxide inhalants should be avoided as they can lead to bowel distention, making visualization difficult and increasing the potential for bowel injury [76, 77]. The use of nitrous oxide inhalant during laparoscopy has also been shown to create a gaseous environment in the peritoneum supportive of combustion, which can be potentially catastrophic if electrocautery is being utilized [78]. A urinary drainage (Foley) catheter and oro- or naso-gastric tube are inserted prior to patient positioning to decompress the bladder and stomach, respectively. The Foley catheter should be secured with tape to the lower leg for patients in the flank position. Oliguria during prolonged laparoscopy is common and the anesthesiologist must be well versed on this issue and avoid “chasing the urine output” as this can lead to fluid overload [79–82]. The upper arm should be the site for placement of the blood pressure cuff and parenteral lines for which rapid access may be necessary. A pneumatic patient warming device can be adhered to the upper extremities and torso or on the lower extremities up to the level of the hips to assist in maintaining patient temperature throughout the case.

Even though the peritoneal surface and bowel is not exposed through a large incision during laparoscopy, heat exchange can still be significant due to the convection flow of the insufflant. Warming of the patient utilizing these devices or insufflant warmers is important to maintain body temperature throughout the case, especially in older patients.

Operative site preparation and draping

The ipsilateral abdomen and flank are shaved from the area of the xiphoid to pubis. A solution of providone–iodine (Betadine) or a similar surface preparation is used to paint the surgical area. The preparation should be wide enough to include the possibility of an open conversion via a flank, subcostal, or midline incision. Special laparoscopic drapes with widened apertures, Velcro straps for cords and tubing, and instrument pockets are commercially available, although a standard paper flank drape can be utilized and the aperture enlarged with scissors to give adequate exposure. Channels can also be created for the light and camera cords, as well as the insufflation tubing, by pulling up redundant drape and clamping it to itself while the cords are brought out through the ends.

Operating room set-up (Figure 81.5)

The operative site and laparoscopic approach determine the variables of the operating room set-up for the

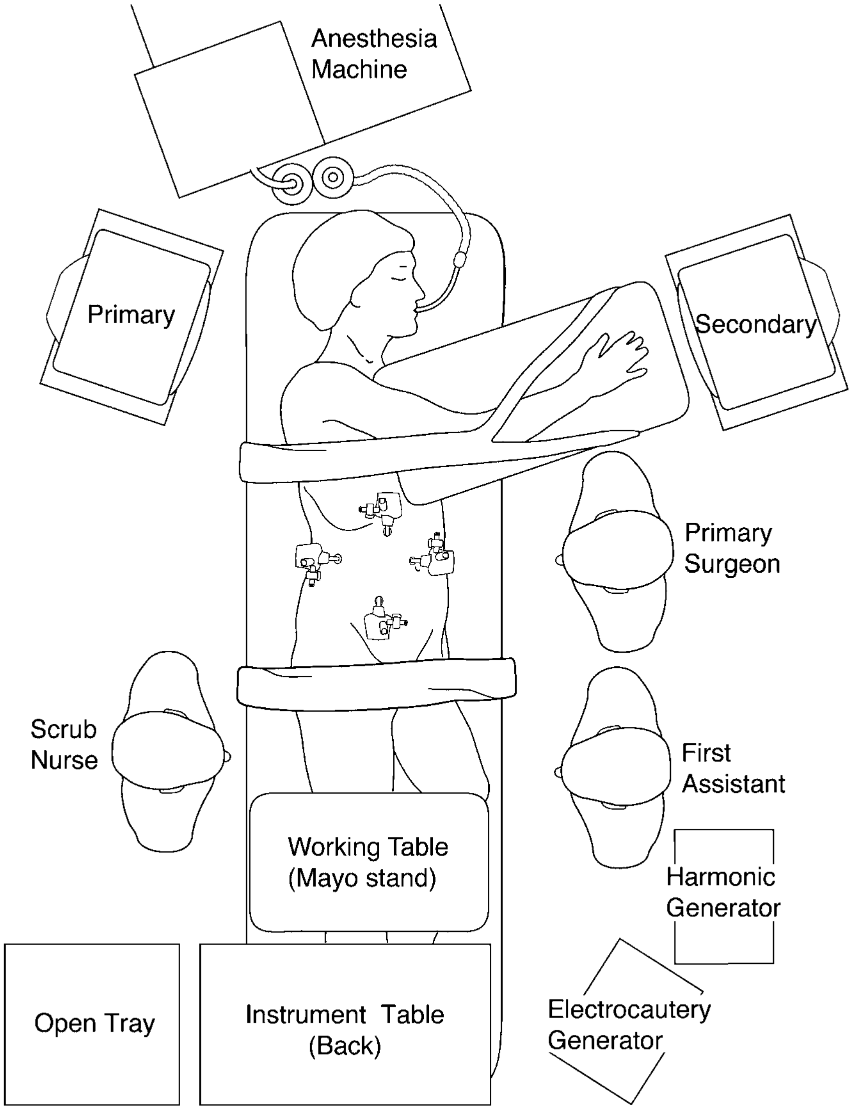

Figure 81.5 Standard operating room set-up for a laparoscopic right-sided transperitoneal renal procedure. See text for details. During retroperitoneal procedures the set-up is essentially a mirror image of the transperitoneal arrangement with the exception of the patient position which remains unchanged. Placement of generators toward the foot of the bed minimizes cord interference with surgeon movements around the operating table.

procedure. The patient is positioned on the operating room table in the flank or semi-flank orientation with their affected side up as outlined above. The surgeon and first assistant stand on the contralateral side of the table to the patient's pathology for transperitoneal procedures and the ipsilateral side for retroperitoneal procedures.

The scrub nurse or technician stands on the opposite side of the table from the primary surgeon, which facilitates passage of equipment directly across the operating table. This arrangement eliminates the need for the operating surgeon to remove their eyes from the primary monitor to reach behind or to their side to receive instruments.

The primary tower containing the insufflator, light source, and camera box is positioned across from the operating surgeon so they can visually inspect the settings as well as the pressure readings throughout the case. The secondary tower is placed on the same side as the primary surgeon for use by the scrub nurse or second assistant. Monitor towers are positioned toward the head of the table and angled back toward the operating surgeon. The height of the monitor must be appropriate for the operating surgeon so upward tilting of the head and subsequent neck fatigue can be avoided. Irrigants are hung on one of the intravenous poles near the head of the patient and the suction canisters are also situated near the anesthetic machine. The scrub nurse places their working table directly over the patient's lower legs. This consists of a Mayo stand on which all frequently used equipment is placed. The back equipment tables are placed end-to-end just lateral to the patient's feet, forming an "L" configuration with the table on the same side as the scrub nurse. The most lateral table contains the open instrumentation.

Simple nephrectomy

The major advantages of the transperitoneal approach to laparoscopic simple nephrectomy over the retroperitoneal approach are a larger working space and anatomy that is familiar to most surgeons. Disadvantages of this approach include the need to dissect and retract the colon, spleen, and pancreas on the left, and the liver and duodenum on the right. There is also an increased risk of visceral complications as a result [63, 83]. The main advantages of the retroperitoneal approach are the limited dissection required of the bowel, avoidance of areas of intraperitoneal adhesion, and rapid posterior access to the main renal artery when performing nephrectomy.

Instrumentation

The instrumentation required is listed in Table 81.3.

Table 81.3 Instrumentation for simple nephrectomy (University of Wisconsin, Madison).

Four nonbladed trocars: two 5 mm and two 10/12 mm (with reducers)
Two 10-mm laparoscopes: one 0° and one 30°
Two 5-mm laparoscopes: one 0° and one 30° (available in the room)
One 14G Veress needle – *transperitoneal*
One trocar-mounted balloon dilation device (Origin Medsystems, Santa Clara, CA, USA) – *retroperitoneal*
One 10/12-mm blunt-tipped cannula (available in the room)
One 10/12-mm visual introducing cannula
One 5-mm curved electrocautery scissors
One 5-mm curved Maryland dissector
One 5-mm curved Harmonic scalpel and generator
One 10-mm locking Babcock
One 5-mm dolphin-nosed grasper
One 10-mm right-angled dissector
One 5-mm toothed locking grasper
One 5-mm electrocautery hook
Two 5-mm laparoscopic needle drivers (available in the room)
One 5-mm diamond flex triangle retractor (Genzyme, Tucker, GA, USA) (available in the room)
One 10-mm PEER retractor (Jarit, Hawthorne, NY, USA)
One Martin arm (available in the room)
One Endo-GIA vascular stapler and two reloads
One 11-mm multiload clip applier
One 5-mm irrigator–aspirator
1 LapSac (Cook Urological, Spencer, IN, USA) (5 x 8 and 8 x 10 inches) (*optional for morcellation of specimens*)
One EndoCatch II bag (Covidien, Mansfield, MA, USA) (*optional for intact specimen removal*)
One grasping needle port closure device
One smoke evacuator valve (Plume-Away: Stryker Endoscopy, San Jose, CA, USA) (*optional*)
One No. 15 blade scalpel and handle
Two fine-toothed pickups
One Tonsil clamp
Two S-retractors
Three 0-Vicryl ties
Four 4-0 absorbable sutures on a cutting needle
¼-inch steri-strips
Benzoin
Open nephrectomy surgical pan

Steps of the procedure: transperitoneal

Step 1: Creation of the pneumoperitoneum and initial entry access

The patient is positioned on the table in a modified flank position, as described above, with the side of the operative pathology placed upwards. A 1-cm incision is made through the skin in the lower quadrant just lateral to the rectus muscle and midway between the umbilicus and the anterior superior iliac crest in nonobese patients. This location may need to be shifted cephalad and lateral in obese patients due to the large abdominal pannus. A small clamp is utilized to spread the underlying subcutaneous tissues down to the level of the fascia. A Veress needle is then inserted perpendicular to the fascial surface. The initial audible "pop" is the puncturing of the fascia, whereas the second represents entry into the peritoneal cavity. This second sound is generated by the snap of the internal obturator of the needle and often can be felt in the introducing hand as well as being heard. The tip of the Veress needle should move freely side-to-side with no perceived resistance, and gentle irrigation and aspiration of saline via a 10-mL syringe should confirm correct positioning of the needle in the peritoneal space. Saline injected into the hub of the Veress needle should flow freely and on removal of the syringe, the column of saline should drain readily into the abdomen under gravity alone ("drop test"). Aspiration of air or enteric contents heralds entry into the bowel by the Veress needle. The abdomen is insufflated to 15 mmHg pressure, elevating the flow rate of CO_2 once it is clear that the initial peritoneal pressures are appropriately low. Initial insufflation pressures should be less than 10 mmHg and higher pressures often indicate entrapment of the needle in the omentum, mesentery, or preperitoneal space.

Vascular and enteric injuries on initial trocar entry of the abdomen have been reported to occur in 0.3% of laparoscopic cases [84]. A review of three series in which 617 access entry injuries occurred demonstrated a 3% death rate following this occurrence, with 59% due to vascular and 41% resulting from bowel injuries [84]. For this reason, we utilize a visual obturator, such as the OptiView (Ethicon Endo-Surgery, Cincinnati, OH, USA) or Visiport (Covidien, Mansfield, MA, USA), to establish initial access. Both allow insertion of the laparoscope into a pistol-shaped introducer placed through the top of a 10/12-mm standard laparoscopic port. The OptiView introducer also comes in a 5-mm size and is shaped like a standard obturator rather than the pistol configuration. Both devices allow visualization of each layer of the abdominal wall as it is traversed. Entry through the peritoneum is heralded by a widening black hole in the center of the visual field through which the device is advanced. During trocar insertion it is important to angle ports toward the area of interest to prevent limitations on excursion and to ensure that the peritoneal and fascial entry points do not line up, therefore limiting the potential for herniation following their removal.

Another option for entry access is utilization of a Hasson cannula via an open technique. This approach usually requires a slightly larger incision to allow adequate exposure of the underlying fascia using the S-retractors. The fascia is incised and a 0 absorbable suture mounted on a semicircular needle, such as a UR-6, is utilized to place a tacking suture through each corner of the fascial incision. The underlying muscular fibers are split using a tapered clamp and the posterior fascial layer is incised, exposing the preperitoneal fat. The thickness of this layer can vary markedly depending upon the habitus of the patient. The preperitoneal fat is spread to expose the underlying peritoneum, which is grasped between two clamps and incised to reveal the peritoneal contents. At this point, we usually replace the tacking sutures to include all of the transected layers. A blunt-tipped open cannula (e.g. Hasson) is then inserted through the peritoneal opening. Variations of this type of trocar are available; however, they usually pass through a cuff that is shaped like an inverted cone, and which is snugged down into the fascial opening and locked in place on the shaft of the trocar. The fascial corner sutures are then wrapped around circular guides on the conical cuff to secure the port in position. Universal or reducers are placed to allow utilization of 5-mm instruments via the 10/12-mm ports.

Step 2: Secondary port placement

After initial access to the peritoneum, a thorough inspection of the abdomen is performed to assess for the presence of adhesions, organomegaly, or altered location of the kidney, which could impact positioning of secondary ports. A skin incision is made for each port that corresponds to the width of the port itself, which can be determined by pressing the mouth of the port into the skin and indenting the epidermis. If the skin incision is too small, it can result in difficult trocar insertion. The increased force required to insert the trocar can ultimately cause rapid uncontrolled entry into the abdomen through a partially collapsed body wall, with resultant injury of the underlying viscera or vasculature. If the skin incision is too large, it can result in leakage of the pneumoperitoneum or inadvertent port dislodgment from the peritoneum. In patients with a nonobese body habitus, a 10/12-mm port is inserted in the periumbilical region. An additional 5-mm trocar is inserted approximately 2 cm below the subcostal margin in the mid-clavicular region. As mentioned above, all ports are shifted lateral and slightly cephalad in markedly obese patients to avoid the abdominal pannus. Placement of ports too close to the ribs or attached cartilage can inhibit movement of the instruments as they encounter the rib cage. The location of secondary port placement is identical for right- and left-handed surgeons.

Three ports are often adequate for performing left-sided nephrectomies; however, an optional 5-mm port can be placed between the 12th rib and the iliac crest in the posterior axillary line to allow for kidney and ureteral retraction by an assistant if so desired. For right-sided nephrectomies, a similarly located fourth port is often necessary for liver retraction (Figure 81.6). Some surgeons prefer to lower the upper mid-clavicular port on the right and move it more medial, while placing an additional 5-mm port above to be used for liver retraction. This is accomplished by passing a locking instrument through this port, underneath the liver, and grasping the cut edge of the peritoneum on the lateral body wall.

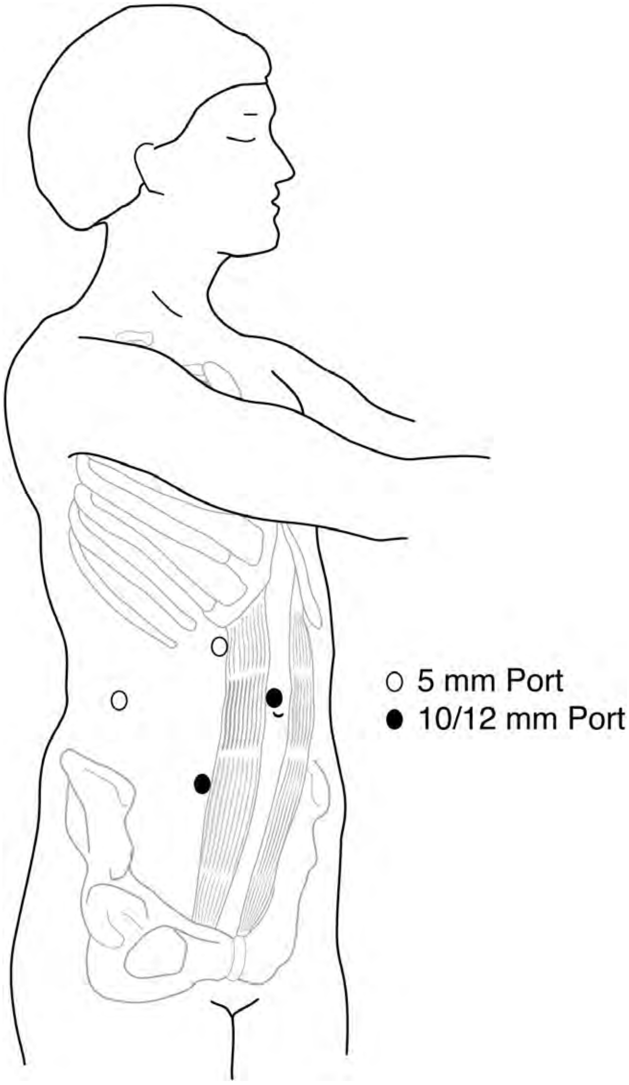

Figure 81.6 Typical laparoscopic port arrangement for a right-sided transperitoneal renal procedure. Trocars are usually inserted near the umbilicus, midway between the iliac crest and umbilicus, just below the costal margin in the mid-clavicular line, and at the anterior axillary line midway between the 12th rib and the iliac crest. Procedure-based determinations of port size will be discussed in each individual operative section. In general, 10/12-mm ports are used at the umbilicus and lower quadrant, whereas 5-mm ports are used at the costal and lateral margins. Modification of port location for obesity involves shifting ports cephalad and lateral to avoid the abdominal pannus.

In cases where a bilateral simple nephrectomy is being performed, a total of five trocars are utilized in an "X" configuration [68, 69]. A 10/12-mm port is inserted at the umbilicus, or several centimeters above, with two ports inserted in the right and left mid-clavicular line several centimeters below the costal margin and at the level of the anterior superior iliac spine [68, 69]. These can either all be 10/12-mm ports or, for a right-handed surgeon, the left subcostal and right anterior superior iliac mid-clavicular ports can be replaced by 5-mm trocars. Conversely, for left-hand dominant surgeons, the left anterior superior iliac spine and right subcostal mid-clavicular ports can be replaced with 5-mm ports. Minor upward adjustments to the location of the ipsilateral lower quadrant port may be required when a transplant kidney is present.

The trocars are appropriately positioned within the abdomen by pulling them back until the insufflation port is just within the peritoneal cavity. Ports can be secured to the abdominal wall by placing a 2-0 absorbable or nonabsorbable suture through the skin, tying an air-knot, then wrapping the suture once around the stop-cock and tying it securely. If securing sutures are utilized, the port is rotated so the stop-cock is furthest away from the area of dissection prior to placing the suture. This prevents the stitch from limiting upward movements of the instruments during dissection. Fascial splitting trocars with a grooved shaft are usually held firmly by the split edges of the fascia and are difficult to dislodge, obviating the need for securing sutures.

Step 3: Exposure of the retroperitoneum

Adequate exposure of the retroperitoneum requires mobilization of several key structures. On the left side, upper quadrant adhesions of the omentum or bowel are often encountered and require mobilization to expose the edge of the splenic flexure and descending colon. The laparoscopic lens is usually inserted through the lower quadrant port and the operating surgeon utilizes the Maryland grasper and dissecting instrument via the periumbilical and subcostal port depending upon their dominant hand. The camera can also be inserted via the periumbilical port site and the lower quadrant port used for working instruments, depending upon the area of

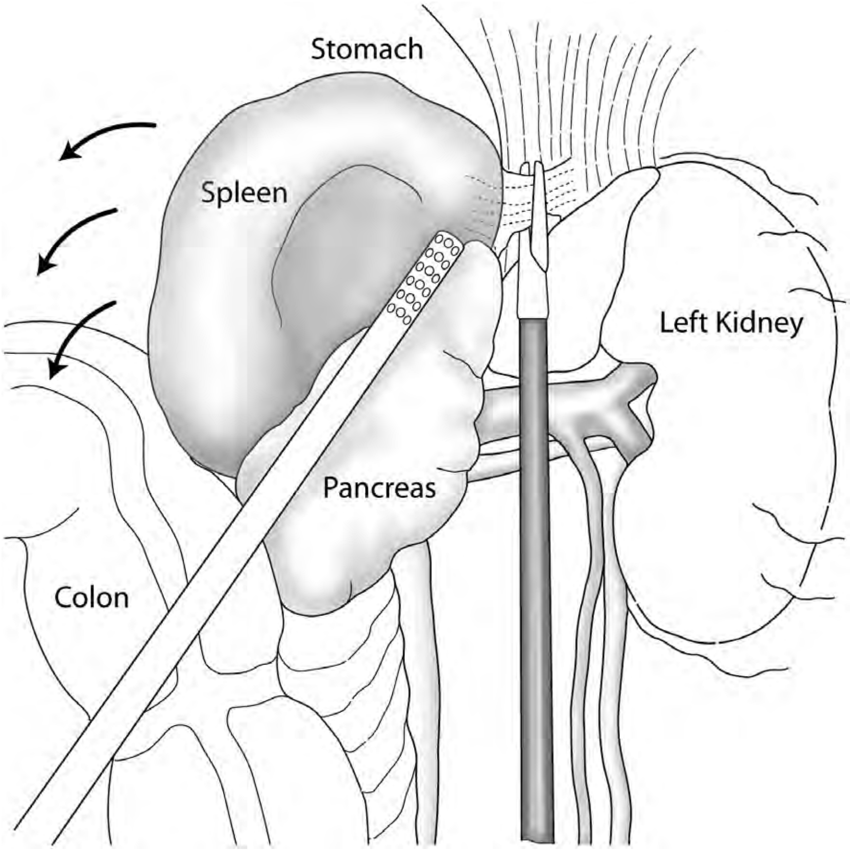

Figure 81.7 Complete exposure of the left retroperitoneum involves complete release of all lateral splenic attachments until the edge of the greater curvature of the stomach is visible. Once released, the weight of the spleen pulls the attached pancreas and bowel medially, protecting these structures while giving complete access to the renal hilum.

the dissection and what port access gives the best visualization. Usually for this part of the dissection, the 0° lens provides a better view of the area of interest, especially as the avascular line of Toldt is incised and mobilization of the colon is carried inferiorly across the pelvic inlet. We typically utilize the Harmonic scalpel for most of the dissection, although the electrocautery shears can also be utilized. The Harmonic scalpel coagulates and divides structures utilizing heat generated from vibrations of the jaws of the instrument at a frequency of 55 500 Hz [85, 86]. This results in intracellular water vaporization, protein denaturation, and release of water vapor instead of smoke. The advantage of this device over electrocautery is its reduced amount of collateral damage, lack of arcing to adjacent structures, reduced impairment of visualization, and its ability to seal and divide vessels as large as 4 mm in diameter [87–89].

In older patients, additional adhesions may be encountered adjacent to the sigmoid colon due to previous bouts of diverticulitis, and care must be exercised not to inadvertently transect enlarged diverticula in this region. The dissection should be carried cephalad to release all lateral attachments of the spleen while gently lifting it up using the shaft of an instrument inserted through the upper port. Splenic mobilization should continue until the greater curvature of the stomach is visualized (Figure 81.7). This is a critical step on the left side because the spleen will act as a dead weight to draw the pancreas and colon medial, thus giving better exposure of the kidney and preventing these structures from being injured. The plane between Gerota's fascia and the posterior aspect of the colonic mesentery is often easily discernable and usually can be teased apart by a combination of blunt and cautery dissection. The vessels within the mesenteric fat and the smoother surface of the thin layer of Gerota's fascia overlying the retroperitoneal fat often provide additional clues to differentiating between these two layers. Separation along this plane should continue down across the pelvic inlet and the colon folded back on its mesentery until the pulsation of the aorta is visualized.

On the right side, the line of Toldt is similarly incised down around the cecum extending into the pelvis. The upper mid-clavicular and periumbilical ports are usually utilized for the dissection. The liver is mobilized by transecting the triangular ligament laterally and the coronary ligament below its lower edge. A 5-mm Diamond Flex Triangle retractor (Genzyme, Tucker, GA, USA) can be utilized for broad-based secure elevation of the liver via the lateral port between the 12th rib and iliac crest. Once positioned beneath the liver, the retractor is secured to the operating table using a robotic (e.g. Martin) arm. The right colon and its mesentery are separated from Gerota's fascia as described for the left-sided dissection. As the colon is rolled medially, the duodenum can be visualized in the upper portion of the retroperitoneum and is kocherized to reveal the underlying inferior vena cava (IVC). It is important to realize that, with rare exceptions, the duodenum overlies the vena cava and requires medial mobilization to adequately expose the right renal vein and upper IVC.

Step 4: Securing the ureter

The remaining steps of the operation are typically performed using a 30° laparoscopic lens inserted via the lower quadrant port. The surgeon operates through the subcostal and periumbilical ports with the dominant hand usually controlling the dissecting instruments. The ureter is identified as one of two tubular structures running in a craniocaudal direction in the retroperitoneum. It usually lies deep and lateral to the similar appearing blue-tinged gonadal vein. After adequate mobilization of the sigmoid colon, the ureter can almost always be visualized after it crosses the iliac vessels and heads into the pelvis. If it cannot be directly visualized, sometimes it provides enough tactile sensation as a firm "band-like" structure in the retroperitoneum to allow localization when a laparoscopic instrument is drawn across it from lateral to medial. Gentle squeezing of a nonpulsatile tubular structure that produces a peristaltic wave confirms that the observed structure is the ureter.

The upward-directed tips of the Maryland dissector are used to elevate the ureter either together or separate from the gonadal vein. On the right side it is preferable to release the gonadal vein medially, so it is not placed on any significant traction during the dissection as this can result in aneurysmal dilation or rupture of its very weak entry point into the IVC. The periureteral tissues can be separated using gentle downward blunt dissection, together with Harmonic coagulation and division whenever more substantial tissue bands are encountered as these often contain ureteral feeding vessels. Complete creation of a window beneath the ureter is facilitated by first opening Gerota's fascia lateral over the psoas musculature. The dissection is carried up along the top of the psoas to the region of the lower pole of the kidney. At this point, we typically secure and divide the ureter by placing a total of three 11-mm clips and cutting between the first and second clips. If easy separation of the gonadal vein and ureter cannot be performed, we divide the ureter, gonadal vein, and periureteral tissues together, utilizing the Endo-GIA stapler with a vascular (2.5 mm) load.

Step 5: Dissection and securing of the hilum

Differences in the vascular anatomy between the right and left kidney require slight alterations in hilar dissection techniques between the two sides. On the left side, the gonadal vein drains into the left renal vein and therefore can be utilized as a convenient method for identifying the surface of this structure. The tissue overlying the anterior surface of the gonadal vein is divided starting at the most proximal part of the vein that is visible. The Harmonic scalpel is ideal for performing this part of the operation as there can be small branches, which enter the gonadal vein medially and can cause troublesome bleeding if the tissues are merely transected. The gonadal vein is traced cephalad until the surface of the main renal vein is exposed on the left.

On the right side, the gonadal vein drains into the vena cava and can be used in a similar fashion to identify the caval surface, although extreme care should be taken in dissecting around this structure due to the fragility of its entry point into the IVC and risk of avulsion. It is important to separate the gonadal vein from the ureter so it can be swept medially, or to clip and divide it several centimeters distal to the IVC to prevent traction at its entry point. Often the surface of the IVC is readily visible after medial mobilization of the duodenum and tracing the gonadal vein is unnecessary. The medial surface of the vena cava should then be exposed and followed cephalad to the entry point of the right renal vein, which often lies higher than anticipated relative to the predicted mid region of the kidney. Once the renal vein is identified, the correct dissection plane directly on the surface of the vein is established by incising the overlying adventitial tissue. The surrounding fibrofatty and lymphatic tissue is grasped and the vein is rolled away and peeled out of the confines of this tissue on both its superior and inferior surfaces using blunt dissection.

On the left side, the adrenal vein branch is identified entering the cephalad surface of the main renal vein and is usually slightly medial to the entry site of the gonadal vein below, although the two sites can emerge from the same location. During this part of the dissection, the assistant can elevate the kidney by grasping the ureter from the lateral-most port if one has been placed. Alternatively, a 2-0 nylon mounted on a Keith needle can be passed through the abdominal wall, followed by the wall of the ureter or periureteral tissues, and back out through the abdominal wall. The suture is then secured with a clamp (Figure 81.8). This can be elevated and lowered as desired to place the hilum on stretch, prevents the need for a lateral trocar on the left, and on

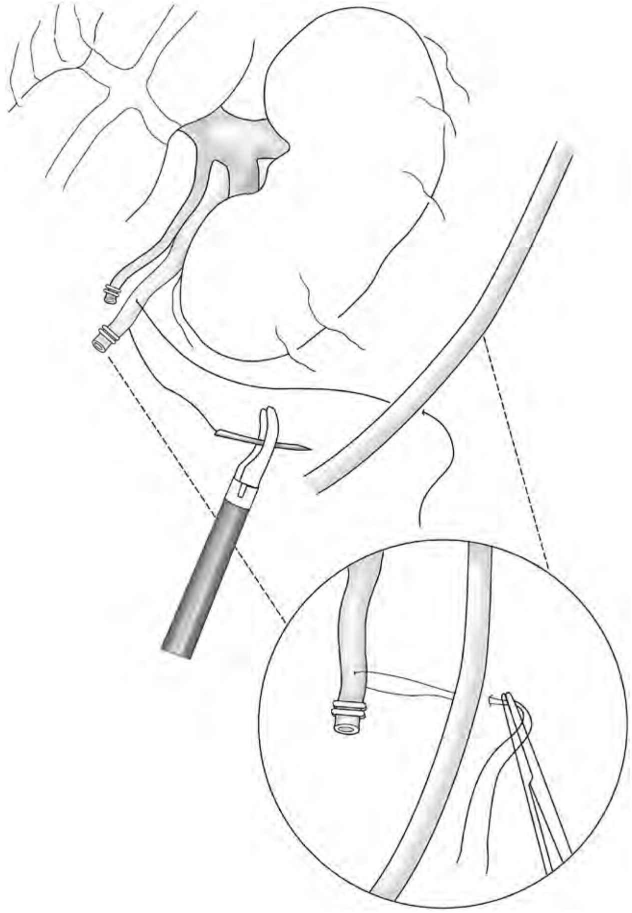

Figure 81.8 A 2-0 nylon mounted on a Keith needle can be utilized to provide variable amounts of kidney elevation without the need of an assistant's instrument. For the left side, this can alleviate the need for a lateral-most trocar. The needle is passed through the abdominal wall, then through the upper ureter or pelvis, and back out of the abdominal wall. The needle is removed and tension on the suture can be altered to provide varying amounts of internal retraction as needed. (Insert) A clamp is placed on the suture ends at skin level to maintain the desired position.

the right enables continuous maintenance of liver retraction through the lateral trocar during this part of the dissection.

Completion of the hilar dissection can be performed utilizing either an anteroinferior or a posterior approach to the renal artery:

Anteroinferior approach

This approach usually requires clipping and dividing of the gonadal, adrenal, and underlying ascending lumbar vein branches on the left side. The ascending lumbar vein branch invariably crosses over the base of the renal artery and tethers the renal vein, making anterior exposure to the artery difficult. A total of four clips are placed on large branch veins and Endoshears are used to divide between the third and fourth clips. The Harmonic shears can be utilized to divide vein branches up to 4 mm in size by placing the Harmonic generator at a variable setting of 2. It is then used to create a coagulative seal at two widely spaced spots on the vessel, followed by coagulation and transection between the sealed areas. Care should be utilized not to inadvertently contact the main renal vein with any portion of the Harmonic shears as this can lead to a thermal puncture.

The adrenal vein branch is similarly isolated and the overlying lymphatic and fibrofatty tissues dissected until a right-angled dissector can be passed behind it. If the degree of fibrosis around the kidney allows it, we release the edge of the adrenal gland from the medial aspect of the kidney prior to clipping and dividing the adrenal vein branch. The Harmonic shears are the ideal instrument for performing this part of the procedure as they efficiently seal the large number of small arteries that feed the adrenal gland. The jaws of the Harmonic are opened and the lower noninsulated jaw is pushed several millimeters into the tissues with the backside of the instrument flush on the adrenal gland to prevent injury to an early arterial branch or late upper pole vein confluence of the renal vasculature. The jaws are then closed and activated. If bleeding occurs from a partially transected vessel, then advancement of the jaws across the area of bleeding is performed to complete the coagulation and transection. The adrenal gland does not swell and ooze as much utilizing this approach as it does if the main adrenal vein branch is transected prior to dividing the medial arterial twigs. If the medial adrenal plane is difficult to establish, the adrenal vein branch is clipped and transected, and dissection of the main renal vasculature is continued. The adrenal vein branch can also be spared in cases where there is adequate vein length between the gonadal and adrenal vein branch entry points to allow either straight or angled application of the Endo-GIA stapler across the main renal vein (Figure 81.9).

As the assistant lifts the ureter and lower pole lateral to place the hilar vessels on stretch, the packet of lymphatic tissue between the artery and vein can be grasped and the artery and vein peeled away. The tissue between the vessels can then be divided by sequential transection using the Harmonic dissector until a right-angled clamp can be readily passed behind the artery and vein. Spreading of the right-angled dissector should confirm the presence of approximately 2–2.5 cm of space to allow easy passage of the Endo-GIA stapler. The hilum is placed on stretch by inserting the irrigator–aspirator through the upper port and placing it between the artery and vein and then lifting (Figure 81.10).

We prefer to use the 2.5-mm vascular Endo-GIA stapler to secure and divide the artery and vein.

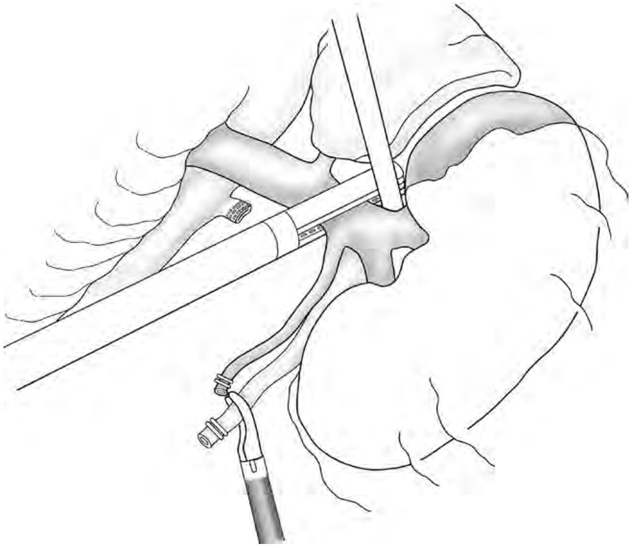

Figure 81.9 Once the renal artery has been secured and transected via a posterior approach, it is often easiest to approach the renal vein anteriorly. The kidney is flipped back into its lateral position and is slightly elevated by the assistant's grasper or a transabdominal nylon suture. The adrenal vein branch can usually be left intact with this approach. To gain extra venous length lateral to the adrenal vein branch to allow application of the endovascular stapler, a blunt instrument such as the irrigator–aspirator can be inserted posterior to the kidney along its medial edge for elevation and lateral retraction, maximizing the space between the edge of the adrenal gland and the upper pole of the kidney.

However, the interlocking Weck clips (Weck Closure Systems, Research Triangle Park, NC, USA) also provide a safe means of controlling the arterial and, in some cases, the venous stump. Three Weck clips are placed on the artery and Endoshear division is performed, leaving two clips on the stay side. Five clips are placed on the vein, dividing between clips so three remain on the stay side. Caution should also be exercised when applying Weck clips to make certain the toe and recipient latch of the clip are entirely across the vessel being secured; otherwise the clip can puncture through the wall of the vessel and result in significant hemorrhage. All surrounding lymphatic tissue should also be released to prevent it from becoming entrapped in the locking mechanism of the clip, resulting in incomplete closure and possible delayed opening.

The device used to secure the hilar vessels can be introduced via the periumbilical or lower quadrant port, depending upon which provides the best angle of approach to the hilum. This is especially important if the stapler does not articulate. The narrow jaw of the stapler is slid between the artery and vein, and the stapler advanced until the black marking line on the lower jaw passes the far wall of the artery and the device is clamped. Visualization of what is contained within the jaws of the instrument prior to firing the staple line and transecting the tissue is facilitated by rotating the device clockwise and then counter-clockwise [90]. This careful inspection is necessary as 50% of the 1.7% of vascular

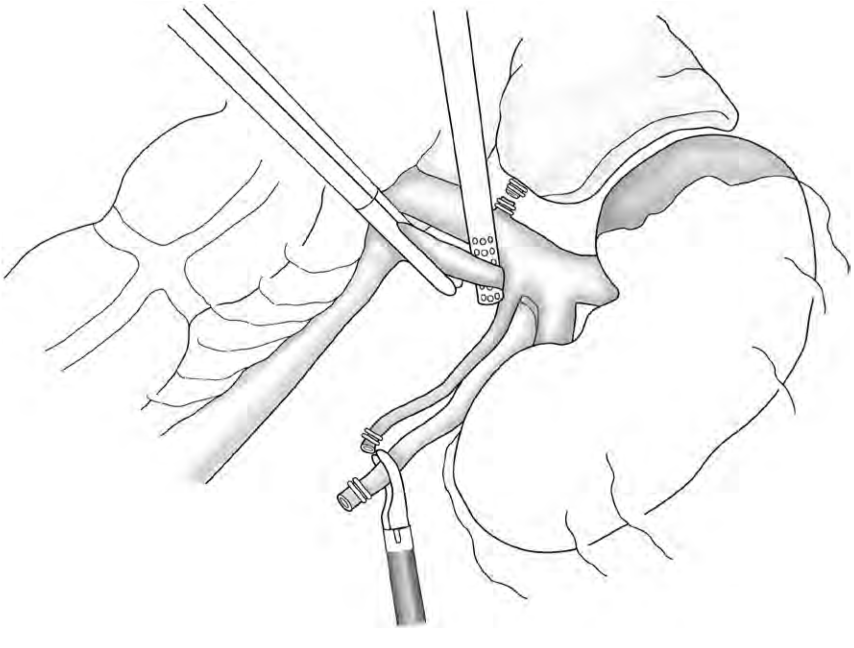

Figure 81.10 The anteroinferior approach to the renal artery usually requires division of the adrenal vein branch to provide enough mobilization of the vein to enable cephalad retraction. Simultaneous elevation of the kidney and separation of the artery and vein can be achieved by insertion of the tip of the irrigator–aspirator between these two structures. The narrow jaw of the endovascular stapler can then be passed between the artery and vein, while the wider jaw passes inferior to the artery. Once the jaws of the stapler are closed, the instrument can be roticulated to confirm correct positioning.

Endo-GIA misfirings are due to application on previously placed clips [90].

Once the artery is transected, the vein should appear collapsed and the specimen should lose some of its turgor. If these changes are not observed, then a careful inspection for accessory arteries should be performed. Once the surgeon is confident that the kidney no longer has arterial flow, the vascular Endo-GIA stapler is passed across the vein in an area free of clips, as well as the distal arterial staple line, and the vein is secured and divided.

The anteroinferior approach to the right kidney is identical to what is performed on the left with the exception that no branches usually enter the main renal vein, and if they do, they are usually small secondary vessels that can be divided using the Harmonic scalpel. Although it is short, the right renal vein will usually accommodate the stapler. Another advantage on the right side is that many times the right renal artery lies slightly below the main renal vein thus facilitating its identification and isolation.

Posterior approach

The posterior approach, or posterior renal artery control [91], is usually employed any time the artery cannot be readily controlled from the anteroinferior exposure. The advantage of this maneuver on the left side is that it gives excellent access to the entire length of the artery, often obviating the need to transect the lumbar vein as the artery can be secured and transected distally. If the renal vein segment is lengthy between the gonadal vein branch and the entry point into the hilum, it may be possible to leave all branches of the left renal vein intact with this approach.

During this maneuver, Gerota's fascia and fat are divided over the lateral aspect of the kidney using the Harmonic shears as outlined in Step 6 below. The fat is released laterally as the kidney is rolled medially. A blunt instrument such as the suction–irrigator should be utilized to roll the kidney, preventing parenchymal injury. If this plane cannot be established due to fibrosis, then a dissection and release lateral to Gerota's fascia, as done during a radical nephrectomy, can be performed. Division of the more cephalad attachments is also required to allow the kidney to be completely flipped medially. Careful inspection of the hilar area usually reveals pulsations of the artery. The fibrofatty tissues overlying the artery are grasped and divided until the smooth surface of the arterial wall is visible. The artery is then shelled out of the surrounding lymphatic tissue until a right-angled dissector can be completely passed behind it and spread to allow placement of the vascular Endo-GIA stapler or Weck clips. The assistant can utilize the lateral port, if present, to push the kidney medial and to keep the hilum on stretch during dissection and securing of the artery.

Once the artery is divided, the kidney is flipped lateral and the assistant elevates the ureter and lower pole of the kidney via the lateral port, or the primary surgeon elevates it via the upper port, to visualize the vein. The upper edge and posterior surface of the main renal vein are dissected free of all surrounding tissue lateral to the gonadal vein branch until a right-angled dissector can be easily passed and spread behind it. This enables clear placement of the Endo-GIA around the vein, which is then transected. The posterior approach to the hilar dissection on the right side is identical to that described on the left.

In cases of severe perivascular fibrosis, several groups have described early *en bloc* ligation and division of the renal artery and vein [92, 93]. The hilum must be skeletonized as much as possible to allow application of the stapler. Shekarriz *et al.* described use of the wider (3.5 mm) clips to accommodate the increased bulk of the dual vasculature and associated hilar tissue [92]. In their series, five patients were managed in this fashion without a significant bleeding event or delayed fistula formation after 2 years of follow-up. Rapp *et al.* described similar *en bloc* division of the hilar vasculature using a laparoscopic Endo-GIA stapler application during laparoscopic nephrectomy or nephroureterectomy in 26 patients, none of whom suffered a fistula or catastrophic bleeding event on mean follow-up of 26 months [93]. We do not generally advocate this approach as other authors have demonstrated the possibility of acute bleeding or delayed arteriovenous fistula formation in a pig model [94].

Step 6: Release of the lateral and cephalad renal attachments

Once the hilum has been secured, the lateral attachments are released if they have not already been freed using the Harmonic scalpel. If the amount of scarring around the kidney does not allow easy dissection between Gerota's fat pad and the renal capsule, the dissection should proceed outside Gerota's fascia similar to a radical nephrectomy. An alternative is to perform a subcapsular dissection for cases of severe perinephric fibrosis [95]. In this technique the parenchyma and collecting system are "shelled out" of the capsule, leaving the posterolateral capsule and all of the surrounding tissue behind. The lateral attachments are released by incising Gerota's fascia parallel to the lateral border of the kidney. The lower pole is then elevated by the surgeon grasping the ureter, or bluntly retracting it, while teasing and transecting tissue from superficial to deep layers. The kidney is rolled medially and the dissection is carried out cephalad. Often complete release of the cephalad attachments requires flipping the kidney to approach it from the anterior and then posterior side. If poor planes exist, an alternative to separation of the cephalad attachments is to create windows in the tissue, separating it into smaller bundles that can be secured using the Endo-GIA stapler. Once it is completely released, the kidney is placed adjacent to the spleen on the left or on the surface of the liver on the right to facilitate entrapment of the specimen.

Step 7: Entrapment with morcellation or intact removal of the specimen

Entrapment with morcellation

It is our preference to morcellate noninfected specimens for which we typically use an EndoCatch II (15 mm) bag (Covidien); however, the smaller EndoCatch I (10 mm) bag (Covidien) can also be utilized. It is easier to operate and is safe for benign specimens. Both bags are mounted on a metal ring, which is delivered by advancing an inner core handle to spring the bag open. An encircling drawstring is then pulled to close the bag on the specimen, tearing it away from the metal ring. The inner core handle is then pulled back, withdrawing the metal ring, and the device is removed, leaving the bagged specimen and drawstring in the peritoneum or retroperitoneum.

Alternatively, a LapSac (Cook Urological, Spencer, IN, USA) can be utilized. The LapSac is made of nylon with a polyurethane inner coating and has been shown to be impermeable to substances such as indigo carmine and albumin, which are smaller than uropathogenic bacteria, providing the option for morcellating specimens that have a strong likelihood of containing infectious organisms [96]. The LapSac should also be utilized if a high-speed tissue morcellator is utilized as it has the highest resistance to mechanical perforation [97]. The 8 x 10-inch LapSac will hold most specimens with the exception of very large (>1000 g kidneys. Noninfected specimens can be morcellated in either a nonpermeable LapSac or an EndoCatch II bag, although the latter is less resistant to perforation [97].

The EndoCatch II bag is inserted through the lower quadrant port site after removing the port as it is too large to fit through the lumen of a 10/12-mm trocar. The assistant opens the EndoCatch II bag with the mouth of the ring just below the kidney, as the surgeon grasps the ureter with the dominant hand and slides the lower pole of the kidney off the spleen or liver into the bag. The upper pole is guided into the bag using a dissector inserted through the subcostal port. Once the kidney and attached tissues are completely within the bag, the drawstring is then pulled to close the device, which is then withdrawn as described above. As already mentioned, care must be taken when morcellating specimens in the EndoCatch bag as its resistance to perforation is minimal compared to the LapSac [97]. An empty sponge stick is an excellent instrument for fracturing and removing the kidney while the bag is kept under careful inspection from the peritoneal side. The entrapment sac is elevated through the trocar site and its edges rolled back to feed it out as the specimen dissipates. Eventually the entire bag can be removed and the port site is then irrigated and the trocar reinserted using the appropriate obturator.

The LapSac is also too large to pass through a standard 10/12-mm trocar, so the periumbilical port is removed, and the sac is rolled and stuffed manually or with the aid of an introducer deeply into the abdomen. The port is reintroduced and the sac is unwound within the peritoneal cavity. A standard 0.035-inch glidewire can be passed twice through the drawstring holes of the LapSac, skipping every other hole on the first pass and traversing the skipped holes on the second pass. The mouth of the sack is positioned below the spleen or liver, depending upon the side of the nephrectomy. The bottom of the bag is pulled down onto the psoas and the inferior lip of the sac is slightly elevated as the laparoscopic lens is inserted into the bag and moved in circular motions to open the sac. The posterior tab of the sac is held up with a grasper inserted through the upper port, and the anterior tab of the sac is held open via the lower quadrant port with the laparoscopic lens inserted via the periumbilical port. The lower pole of the kidney is then slid into the sac with the aid of a grasper inserted via the lateral-most port. Once the kidney is pushed deeply into the sac, the drawstring is brought out via the lower quadrant port site and the bag is elevated through the skin. If a potentially infected specimen is morcellated, antibiotic-soaked towels are placed around the port site as the morcellation process proceeds, and gloves and gowns should be changed following the morcellation and the port site irrigated with antibiotic solution. Dirty instruments used in the morcellation process should be removed from the surgical field. Large ADPKD kidneys require fluid decompression prior to extraction by either morcellation or intact specimen removal.

Entrapment with intact removal

In some cases, such as an infected kidney bearing a large staghorn calculus, it may be desirable to remove the specimen intact. Clayman *et al.* demonstrated that removal of the specimen via a lower quadrant incision connecting the port sites resulted in an increased incidence of hernia formation [98]. We prefer to use a periumbilical or Pfannenstiel incision for intact extractions. In this technique, a standard incision is made in one of these two locations down to, but not through, the peritoneum. A purse-string 2-0 Vicryl suture is placed in the exposed center of the peritoneum or around the periumbilical port site if utilized. The peritoneum is then incised with the cautery, or the port removed, and a large EndoCatch II bag is inserted through the peritoneal opening. The purse-string suture is tied down around the sleeve of the EndoCatch device allowing re-establishment of the pneumoperitoneum. The kidney is then captured in the EndoCatch as previously described, and the peritoneal incision is widened and the specimen removed. Alternatively, the surgeon's arm can be inserted into the incision until the forearm prevents loss of the pneumoperitoneum, and the kidney can be grasped with the introduced hand and removed [99]. In this method the peritoneal incision should be just large enough to allow introduction of the forearm. After removal of the specimen, the peritoneum is closed using a running 2-0 Vicryl, and a moistened laparotomy pad is placed in the incision.

Step 8: Exiting the abdomen and port closure

Final inspection of all areas of dissection is performed under low insufflation pressures of 5 mmHg to look for venous hemorrhage that might otherwise be compressed by the pneumoperitoneum. Careful inspection of the hilar vessel stumps is also performed. The Harmonic shears can be utilized for obtaining hemostasis of localized areas of bleeding away from the main hilar vascular stumps. We place a half-sheet of oxidized regenerated cellulose (Surgicel; Johnson & Johnson, Arlington, TX, USA) at the area of the transected vessels, along the margin of the adrenal gland, and any other areas where persistent venous oozing is noted. After hemostasis is deemed adequate, the pressure of the pneumoperitoneum is increased to 15 mmHg. It is not necessary to reperitonealize the colon as this occurs rapidly with or without suture placement.

We place a 0-Vicryl closure suture at each of the 10/12-mm port sites with the aid of a fascial closure device, such as the Carter–Thomason (Inlet Medical, Trumball, CT, USA) [100], which has been shown to be one of the more efficient means of closing the fascia in animal and clinical studies [101, 102]. The other advantage of this type of device is that it allows full-thickness closure of the port site, including both fascia and peritoneum, which is important as subfascial herniations have been reported following laparoscopy [103, 104]. The Carter–Thomason can be utilized in one of several ways, the easiest of which is to grasp the Vicryl closure stitch 1–2 cm back from its end and to pass a full-thickness simple suture through the center of the cut fascial edges on either side of the port, leaving the port in place. A grasper is utilized by the assistant via one of the other ports to hold the end of the suture, and the device is then removed. The Carter–Thomason grasping needle is reinserted through the other side of the fascia, the suture is transferred to the jaws of the device within the abdomen, and it is withdrawn and tagged with a clamp. A conical guide with holes for passage of the closure needle through the fascia is also available to facilitate use of this device, but it can only be utilized after removal of the port, which then needs to be reinserted after placement of the stitch. The final alternative is to remove the port and to use the index finger of the non-dominant hand inserted into the fascial defect to guide insertion of the needle, which is pinched between the thumb and the inserted index finger while maintaining the pneumoperitoneum. An advantage to utilizing the finger is the ability to feel the edges of the fascial opening, which are not always parallel to the skin incision when fascial splitting or nonlinear cutting trocars are utilized. The instrument companies and some surgeons advocate that it is not necessary to close the fascia for fascial splitting trocars [105]; however, we described a case of port site herniation via such a port site following a laparoscopic donor nephrectomy [106]. As a result we now place a closure suture at nearly all 10/12-mm fascial defects. The 5-mm port is removed first under vision, so a suture can be placed using the other ports if bleeding is observed.

The last port closed is the lower quadrant port through which the pneumoperitoneum is evacuated to prevent CO_2 irritation of the diaphragm. The patient is placed in the slight Trendelenburg position and is given several extended large volume respirations to evacuate as much of the retained insufflant as possible. Once complete evacuation of the CO_2 has been performed, the closure suture is elevated and the port is pulled out of the abdomen while the laparoscope is left within the peritoneum. The laparoscope is then slowly withdrawn in a perpendicular axis to the patient, making sure bowel and omentum drop away as the laparoscope passes out through the fascial opening. The final fascial suture is then tied and the incisions are irrigated with antibiotic solution. If a Pfannenstiel incision was created, the fascia is closed using a #1 Polydioxanone suture and the subcutaneous tissues reapproximated with several interrupted 3-0 absorbable sutures. Each incision site is injected with 0.25% bupivicaine (Marcaine) and a subcuticular closure is performed using 4-0 absorbable suture. Steri-strips are placed with the aid of benzoin followed by a band-aid at each of the port sites.

Steps of the procedure: retroperitoneal

Step 1: Initial entry access and creation of the pneumo-retroperitoneum

McDougall *et al.* describe the use of a Veress needle inserted into the retroperitoneum at Petit's triangle (inferior lumbar triangle) just above the iliac crest in the posterior axillary line [107]. A CO_2 pneumo-retroperitoneum is created to 15 mmHg pressure and the initial 10/12-mm port is inserted at this site. More commonly, an open retroperitoneal access is utilized by first making a 1.5–2-cm incision just below the tip of the 12th rib, then spreading the underlying fat down to the lumbodorsal fascia using two S-retractors. The lumbodorsal fascia is then punctured using a Tonsil clamp and the underlying muscle fibers split until the fat of the retroperitoneal space can be visualized. A 0-Vicryl suture mounted on a semi-circular (UR-6) needle can be inserted through each fascial edge to assist in securing the Hasson-type cannula. The surgeon inserts an index finger into the retroperitoneum, sweeping away the underlying fat until the smooth surfaces of the psoas and quadratus lumborum musculature are palpated, and the edge of the peritoneal envelope is swept as far medially as the length of the inserted finger will allow. At this point many authors favor use of a trocar-mounted balloon dissection device (e.g. Origin Medsystems, Santa Clara, CA, USA) to facilitate creation of the retroperitoneal space [108]. This device consists of a trocar with an attached lucent balloon that is positioned between the posterior surface of Gerota's fascia and the psoas muscle, and is then inflated with air while performing direct vision monitoring via a laparoscope inserted through its lumen (Figure 81.11). The amount of instilled air depends on the size of the patient, with 400–600 mL instilled in pediatric and 800–1000 mL in adult patients [70]. Positioning of the balloon outside of Gerota's fascia has been shown to give rapid and reliable access to the posterior aspect of the renal hilum.

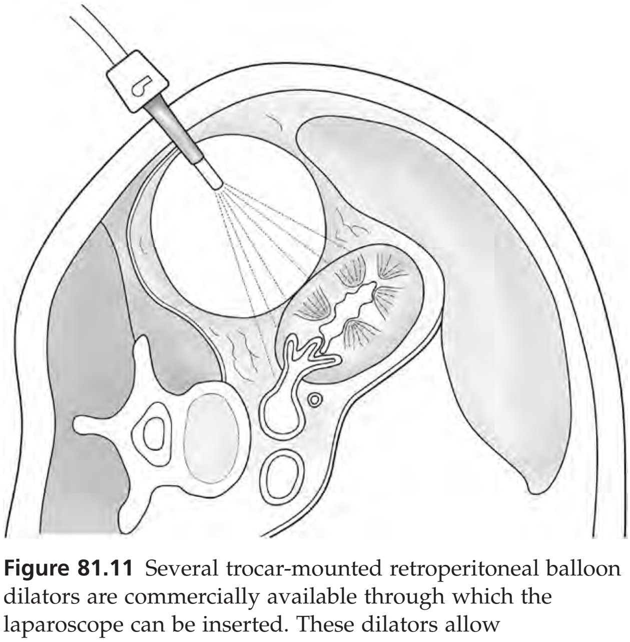

Figure 81.11 Several trocar-mounted retroperitoneal balloon dilators are commercially available through which the laparoscope can be inserted. These dilators allow confirmation of correct balloon positioning and direct inspection of the retroperitoneal contents as the dilation is being performed.

Alternative methods for creating the retroperitoneal space include insertion of a red rubber catheter on which the cut index finger of a no. 7 surgical glove has been tied [72]. This finger balloon is sequentially filled with saline to the desired volume of 500 mL or less to facilitate dissection. Pressure–volume laboratory studies demonstrated similar intraballoon pressures between the index finger of a no. 7 and the middle finger of a no. 8 surgical glove after inflating with 500 mL saline [72]. No ruptures were noted *in vitro*. During clinical cases, a total of 38 patient procedures were performed using this method and finger balloon rupture occurred in three; all had undergone prior retroperitoneal surgery [72]. In one patient, all of the fragments could not be retrieved; however, no complications resulted during 6 months of follow-up.

McDougall *et al.* advocate use of the middle finger of a no. 8 Triflex surgical glove (Baxter Healthcare Corporation, Valencia, CA, USA), for which laboratory tests demonstrated that balloon pressures never exceeded 20 mmHg during filling to 2000 mL and the burst point was approximately 4000 mL [107]. They reported the use of their finger balloon in 12 retroperitoneal renal procedures during which they inflated it with 1000 mL of saline and experienced no balloon ruptures.

The initial port can also be inserted at the retroperitoneal entry site and the CO_2 insufflation begun at 15 mmHg pressure while the laparoscope is used to push into and sweep down the attachments between the posterior surface of Gerota's fascia and the psoas muscle [109]. These latter two methods do not, however, provide the same degree of anteromedial displacement of the kidney within Gerota's fascia that is so critical for rapid identification and access to the hilar structures.

A blunt-tip Hasson cannula may be utilized as the primary port at the initial entry site for insertion of the laparoscope. The fascial tacking sutures are wrapped around the guides on the inverted conical sleeve of the Hasson cannula, which is then seated down into the incision prior to locking it on the port sleeve to help prevent leakage of the pneumo-retroperitoneum. Other authors favor use of the Origin 10/12-mm blunt-tip cannula (Origin Medsystems, Santa Clara, CA, USA) at the initial entry site, as the internal retention balloon snugs tight against the inner aspect of the abdominal wall by sliding down the adjustable external cuff, creating an excellent seal resistant to leakage of CO_2 [109]. The retroperitoneum is insufflated to 15 mmHg pressure and the 10-mm 30° laparoscope is inserted.

Step 2: Identification of anatomic landmarks and secondary port placement

In a review of visualized anatomic landmarks following initial retroperitoneal access in 18 patients at the Cleveland Clinic, Sung *et al.* reported visualizing the psoas muscle (100%), lateral peritoneal reflection (83%), ureter (61%), renal artery pulsations (56%), aortic pulsations (90% on the left) and IVC (25% on the right) [110]. Due to the proximity of the port site placement during retroperitoneal procedures (6–8 cm) [70], it is often difficult to adequately visualize the site of port entry when introducing additional trocars, even with the 30° lens.

A reliable method of bimanual controlled introduction has been described [108]. In this method, the primary port is removed and the index finger of the nondominant hand is inserted and used to ensure that the peritoneal envelope is swept away as two ports are introduced at the mid-axillary line, one approximately two finger-breadths above the iliac crest and one just off the tip of the 11th rib (Figure 81.12). Placement of the lower mid-axillary port too close to the edge of the iliac wing will result in frustrating limitations of instrument excursion by the bone. The inserted finger can be protected using an S-retractor as described by Gill [70], which is especially important if bladed trocars are used. The use of fascial splitting trocars reduces the risk when performing this maneuver. A third trocar is then inserted just lateral to the palpated edge of the psoas muscle. The size of the inserted ports depends upon the dominant hand of the primary surgeon and the side on which the operation is being performed (Figure 81.12).

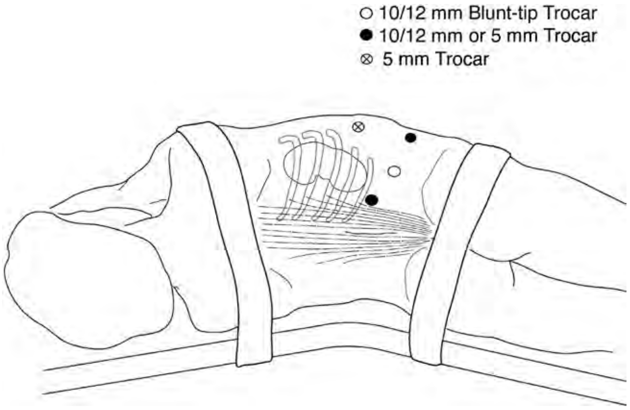

Figure 81.12 Typical trocar arrangement for a retroperitoneal renal procedure. The initial port is a blunt-tip Hasson-type inserted several finger-breadths below the tip of the 12th rib. Once the retroperitoneal space has been created and the peritoneal envelope swept medially, an additional port is inserted several finger-breadths below the 12th rib just lateral to the paraspinal muscles and slightly below the blunt-tipped port in the posterior axillary line. For right-sided procedures, this is a 5-mm port for a right-handed surgeon and a 10/12-mm port for a left-handed surgeon. For left-sided procedures, this is a 10/12-mm port for a right-handed surgeon and a 5-mm port for a left-handed surgeon. A 5-mm port is inserted just off the tip of the 11th rib in the mid-axillary line. A fourth port is inserted two finger-breadths (~3 cm) above the iliac wing in the mid-axillary line. For right-sided procedures, this is a 10/12-mm port for a right-handed surgeon and a 5-mm port for a left-handed surgeon. For left-sided procedures, this is a 5-mm port for a right-handed surgeon and a 10/12-mm port for a left-handed surgeon.

Step 3: Incision of Gerota's fascia and identification of hilar vessels

The laparoscope is inserted through the trocar located just off of the tip of the 12th rib and the surgeon works through the lower mid-axillary and posterior ports. The assistant retracts the kidney anterolaterally through the upper mid-axillary port to place the hilum on stretch (Figure 81.12). A longitudinal incision is made through Gerota's fascia and the psoas muscle is traced cephalad until the vigorous pulsations of the renal artery are visible beneath their fibrofatty, lymphatic covering. Early posterior identification of the artery is one of the primary advantages of the retroperitoneal approach. Once the artery is identified, the Harmonic scalpel is utilized to gently tease and divide the overlying fibrofatty tissue until the wall of the artery is encountered. The artery is then dissected circumferentially at the surface of its muscular coat until a right-angled or Maryland dissector can be readily passed behind it and spread to provide adequate space to secure and divide the vessel.

Step 4: Securing of hilar vessels

As described previously for the transperitoneal approach, options for securing the main renal artery include the 2.5-mm Endo-GIA stapler or self-locking Weck clips. As always, care must be exercised to be certain the tips of the stapler are visualized, as inadvertent clamping of cephalad and medial tissue on the right can result in partial transection of the IVC, and on the left the superior mesenteric artery can be injured.

Once the artery has been divided, the kidney should become noticeably less tense and the more anteriorly located main renal vein can be visualized. On the left side it may be necessary to circumferentially dissect, clip, and divide the adrenal, gonadal, and/or lumbar vein branches to allow adequate dissection and mobilization of the main renal vein for application of the Endo-GIA stapler. The vein should appear collapsed and the kidney decompressed; if it does not, a thorough inspection caudal and cephalad to the main renal artery should be performed to ensure that no accessory arteries are present. If accessory arteries are identified, these must be secured and transected prior to stapling the main renal vein to prevent engorgement and vigorous bleeding from the kidney and vein stump. Once the collapsed main renal vein has been adequately mobilized, the 2.5-mm Endo-GIA stapler is utilized to secure and divide it. Again, it is critical to observe the entire length of the stapling device to prevent accidental injury of anteromedial structures.

Step 5: Transection of ureter and release of inferior attachments

The fibrofatty tissues above and below the transected hilar vessels are teased away with the Harmonic scalpel. The ureter and gonadal vein, if its entry point remains with the specimen, are identified medially on the psoas, dissected circumferentially, clipped, and divided. At this point the ureter can be grasped and retracted laterally, while the entire lower pole is freed of all its attachments using the Harmonic scalpel.

Step 6: Release of cephalad attachments and adrenal gland

Downward traction on the ureter helps to expose the upper pole of the kidney, which is then separated from the adrenal gland by inserting the jaws of the Harmonic scalpel along the juncture of the two, allowing time for adequate hemostasis. The ureter is alternately held lateral and medial while applying downward retraction as indicated to provide adequate exposure of the dissection plane. Once the adrenal gland is released, no significant attachments to the kidney should remain and it can be moved freely in the retroperitoneum.

Step 7: Entrapment with morcellation or intact removal of the specimen

Once the specimen is free within the retroperitoneum it can be placed in an entrapment sac and either delivered intact by enlarging the primary or lower mid-axillary port [70] or it can be morcellated as described for transperitoneal procedures. Use of the LapSac is cumbersome given the confines of the retroperitoneal space, but it can be introduced via the 10/12-mm port site and positioned with the closed end directed deep into the pelvic extent of the extraperitoneal space while the kidney is kept high in the retroperitoneum. The ureter and lower pole are gently swept into the bag in a longitudinal orientation as the surgeon holds two of the tabs on the mouth of the bag to keep it open as the kidney is delivered inside. As discussed for the transperitoneal approach, the advantage of using this bag for removal of benign specimens include its resistance to mechanical perforation and lack of permeability to uropathogens when morcellating infected specimens [96, 97]. Gill describes the use of one of the ring-mounted entrapment sacs (e.g. EndoCatch I or II), which can be inserted at one of the 10/12-mm port sites, the specimen entrapped, and the port site enlarged to allow intact removal [110]. If the port site is enlarged to deliver the specimen intact, the fascial incision is then closed using a running #1 Polydioxanone suture.

Step 8: Exiting the retroperitoneum and port closure

The pneumo-retroperitoneum is lowered and the areas of dissection are once again inspected under both high (15 mmHg) and low (5 mmHg) insufflation pressures. Once hemostasis is felt to be adequate, the pneumo-retroperitoneum is evacuated, the ports are removed, and the S-retractors are utilized to put a simple fascial closure stitch at the remaining 10/12-mm port site. Since the peritoneum is not violated, full-thickness closure utilizing a device such as the Carter–Thomason is not required and is often difficult to use due to the proximity of the ports. The remainder of the skin closure and dressings is as described for transperitoneal nephrectomy.

Postoperative care

The patient is usually encouraged to begin ambulation or to at least sit up in a chair on the night of their surgery. That night, or the following day, clear liquids are initiated if bowel sounds are present and the patient is ambulated at least per shift. Pain is controlled with the use of parenteral agents or a patient-controlled analgesia device. We maintain compression devices and Ted Hose while the patient is at rest in bed or sitting in a chair. The orogastric tube is removed immediately following the operation and the Foley catheter is typically removed once the patient is ambulating on postoperative day 1. If the patient has a history of voiding abnormalities, we often wait to remove the Foley catheter until the second postoperative day. Broad-spectrum antibiotic coverage is continued for 24 h following surgery and is converted to a week-long course of an oral agent appropriate for the patient's situation should a suspected infection exist. We typically use a sulfa-based agent or a fluoroquinolone. If clear liquids are tolerated without bloating and active bowel sounds are present, the patient's diet is advanced to general on postoperative day 2, and they are switched to oral pain medication. Once the patient is tolerating a regular diet, their pain is well-controlled on oral agents, and they are passing flatus, they are discharged from the hospital. Typically, discharge occurs on postoperative day 2 or 3, and is most commonly delayed by slow return of bowel function. If active flatus is not occurring by day 2, we help stimulate its return by administering a bisacodyl suppository.

Results

Laparoscopy for benign disease is being offered at many academic centers, as well as community-based hospitals. The results of several larger series of laparoscopic simple transperitoneal and retroperitoneal nephrectomy are summarized in Tables 81.4 and 81.5. Operative times typically average 2.5 h [111], although mean reported times of 7 h demonstrate the potential complexity of these dissections [113]. A five-fold reduction in the amount of narcotic analgesia relative to open nephrectomy, as demonstrated by McDougall and Clayman [120], with convalescence times of 2–4 weeks reflect the benefits of laparoscopy. Mean length of stay in most reported series still averages slightly more than 3 days [113], and slightly longer in European and Asian series, which in large part may be a reflection of differing criterion for discharge [114].

A review by Landman *et al.* of three comparative series (one European) totaling 67 laparoscopic simple (50 transperitoneal; 17 retroperitoneal) versus 55 retroperitoneal open nephrectomies for benign disease demonstrated mean operative times of 241 and 146 min, respectively [121]. Length of stay and time to full recovery averaged 5.1 and 30.8 days for the laparoscopic group and 8.5 and 145 days for the open group, respectively. Open conversion was required in five (7.5%) of the 67 patients, which is similar to the 8% open conversion rate in 106 transperitoneal laparoscopic simple nephrectomies reported by Eraky *et al.* [2]. As stated earlier, many simple nephrectomies are far from simple due to the scarring associated with the pathologic process. Indeed, the underlying renal pathology has been shown to have a direct correlation to the incidence of conversion, with renal tuberculosis, post-traumatic renal atrophy, infarcted kidneys, and xanthogranulomatous pyelonephritis having an open conversion rate of 89% in one large multi-institutional German study [122].

Eraky *et al.* reported one of the largest single institution experiences with transperitoneal laparoscopic simple nephrectomy (Table 81.4) [2]. These authors performed a total of 106 laparoscopic transperitoneal nephrectomies for primary indications consisting of chronic pain, recurrent infection, or associated hypertension. The open conversion rate in their series was 8%, with five cases due to failure to progress secondary to adhesions, three due to bleeding, and one due to inability to entrap the specimen. All specimens were entrapped and manually morcellated in a LapSac. Mean operative time was 186 min overall, but averaged 217 min for the initial half of the series and 154 min for the latter half. There were four major complications, including a pulmonary embolism, colonic perforation requiring colostomy, and an infected hematoma requiring percutaneous drainage. The mean hospital stay was 2.9 days.

Hemal *et al.* reported one of the largest single-institution experiences with retroperitoneal laparoscopic simple nephrectomy (Table 81.5) [1]. These authors performed a total of 185 laparoscopic retroperitoneal nephrectomies or nephroureterectomies for benign conditions, including 154 nephrectomies for such indications as UPJO (77), stone disease (53), ureteral stricture (9), tuberculosis (7), dysplasia (4), ectopic ureterocele (2), and renovascular hypertension (2). A total of 18 patients required conversion to open surgery (9.72%) with 14 of these conversions occurring during the first 100 cases. Four conversions were urgent (three for bleeding; one for colon injury) and 14 were elective due to failure to progress as a result of adhesions (12) or loss of the pneumo-retroperitoneum secondary to a peritoneal rent (2). The average operative time for completed laparoscopic procedures was 100 min and the mean blood loss was 133 mL. Four patients required a blood transfusion. Seven major complications (3.78%) were reported, including the four which led to an open conversion and a retroperitoneal collection requiring exploration and drainage. Thirty-two minor complications (16.2%) occurred, including the two peritoneal violations that led to open conversion [1].

Fornara *et al*. reported their series of 11 kidney transplant patients who underwent bilateral laparoscopic transperitoneal native nephrectomies [68]. Mean operative time was 195 min and blood loss was 345 mL. One patient required open conversion due to bleeding from the renal artery. Complications included a retroperitoneal hematoma requiring a 2-unit blood transfusion, fever of unclear etiology, and a urinary tract infection. Postoperative renal function was stable in all patients and the mean analgesia requirement was 14 mg morphine equivalent and hospital stay 4.2 days. This compared favorably to 10 patients at the same institution who had bilateral open nephrectomies. The open surgery group required three times the amount of postoperative analgesia and had a mean hospital stay of 10.7 days [68].

As mentioned previously, two infectious conditions of the kidney for which the laparoscopic approach has demonstrated questionable results include xanthogranulomatous pyelonephritis (XGP) and renal tuberculosis. XGP is an intense infectious/inflammatory condition of the kidney associated with chronic infection, obstruction, and the presence of renal calculi. CT scan imaging

Table 81.4 Results of laparoscopic simple nephrectomy: transperitoneal.

Series	Number	Operative time (mean, min)	EBL (mean, mL)	Open conversions	Extraction method(s)	Analgesia (morphine equiv, mg)	Complications (minor)	Complications (major)	LOS (mean, days)	Convalescence (mean, days)
Eraky *et al.* [2]	106	186	–	9 (8%)	Morcellated	–	24 (33%)	4 (3.8%)	2.9	–
Keeley *et al.* [111]	79	146	–	4 (5%)	Intact	–	13 (16.5%)	1 (1.3%)	4.7	–
Ono *et al.* [112]	27	265	455	3 (11.1%)	Morcellated	12.9 mg* pentazoline IM	–	6 (22%)	10[a]	17
Kerbl *et al.* [113]	20	355	200	1 (5%)	Morcellated	54	2 (10%)	5 (25%)	3.6	28
Rassweiler *et al.* [114]	18	206.5	–	2 (11.1%)	Intact	1 vial over 2 days	3 (16.7%)	4 (22.2%)	6.6	24
Parra *et al.* [115]	12	145	140.7	1 (8.0%)	8% Morcellated	14	1 (8.3%)	1 (8.3%)	3.5	16
Total	**262**	**187.9****	–	**20 (7.6%)**	–	–	**43 (16.4%)**	**21 (8%)**	**4.3****	–

*21 patients not requiring a laparotomy.
**Weighted averages.
EBL, expected blood loss; LOS, length of stay.

Table 81.5 Results of laparoscopic simple nephrectomy: retroperitoneal.

Series	Number	Operative time (mean, min)	EBL (mean, mL)	Open conversions	Extraction method(s)	Analgesia (morphine Equiv, mg	Complications (minor)	Complications (major)	LOS (mean, days)	Convalescence (mean, days)
Hemal *et al.* [1]	185	100	133	18 (9.7%)	Intact	–	30 (16.2%)	7 (3.8%)	3.0	–
Gaur *et al.* [116]	38	131.8	83.5	6 (16%)	–	Mean 2.4 days	16 (42.1%)	1 (2.6%)	2.7	13.3
Doublet *et al.* [117]	36	95	–	0	Intact	–	0	1 (2.7%)	3.7	–
Ono *et al.* [118]	20	198	135	0	Morcellated	None – 4, 33 mg pentazocine – 16	0	1 (5%)	8.0	18.9
Rassweiler *et al.* [114]	17	211.2	–	1 (5.9%)	–	0.5 vials over 1 day	2 (11.8%)	3 (17.6%)	6.3	21
McDougall *et al.* [107]	9	348	235	0	Morcellated	39	1 (11.1%)	1 (11.1%)	3.5	7
Gasman *et al.* [119]	8	120	65	0	Intact	22.5 mg	0	0	2.6	–
Total	**308**	**125.2***	–	**25 (6.6%)**	–	–	**49 (15.9%)**	**14 (4.5%)**	**3.6***	–

*Weighted averages.
EBL, expected blood loss; LOS, length of stay.

usually demonstrates enlargement of the kidney with a "bear-paw" appearance resulting from fat-laden macrophage replacement of the collecting system (see Figure 81.1). The disease results in an intense fibrotic response around the kidney with adhesion to adjacent structures, including bowel, adrenal gland, liver, IVC, aorta, spleen, pancreas, and psoas muscle. Fistula formation to the colon or skin of the flank has been reported [123, 124]. A review by Bercowsky *et al.* demonstrated a 60% complication rate in five patients undergoing laparoscopic removal, with a mean operative time of 6 h, bringing into question the utility of laparoscopy in this setting [125].

Reported open conversion rates for attempted laparoscopic nephrectomy for renal tuberculosis are as high as 80% in the most experienced hands [122], with spillage of caseating material reported by several groups [126, 127]. The need for extended multidrug therapy following this type of occurrence and the difficulty of these operations makes this another questionable disease for which laparoscopic nephrectomy should be utilized.

ADPKD represents a challenging condition due to the size of the kidneys, with many extending across the midline or deep into the pelvis [27, 128]. The significant size of these specimens requires initial cyst decompression utilizing the Harmonic shears, with irrigation and aspiration of the released fluid to allow adequate exposure of the hilum for dissection [129]. A comparison of 10 ADPKD kidneys removed laparoscopically compared to 10 removed with the open procedure demonstrated no complications in the laparoscopic group with a significant reduction in hospital stay (2.6 versus 6.6 days, respectively) [130]. Mean laparoscopic times were, however, significantly longer than in the open group (247 vs 205 min) with one case converted to an open procedure.

Complications

The reported complications with establishment of transperitoneal and retroperitoneal access for any laparoscopic approach can also occur during laparoscopic simple nephrectomy. In a review of 2407 laparoscopic cases in urology, Fahlenkamp *et al.* demonstrated a 0.2% incidence of adjacent organ perforation [131]. This is similar to the 0.3% rate access-related injuries reported during gynecologic surgery [132, 133]. The use of an open blunt-tip trocar access as described by Hasson [134] is not a guarantee against injury. Penfield reported a 0.06% bowel injury rate using an open access technique in 10 840 laparoscopic cases [135]. Two aortic injuries have also been reported using the Hasson technique [136].

Several reviews have specifically assessed the complications inherent to nephrectomy and stratified them relative to the type of nephrectomy performed [63, 122, 137]. Siquiera *et al*. described their experience with 213 laparoscopic nephrectomies, which included 84 live donor nephrectomies, 61 radical nephrectomies, 55 simple nephrectomies, and 13 nephroureterectomies. The majority (196) were performed via a transperitoneal approach with the exception of 17 retroperitoneal simple nephrectomies. A total of 16 major (7.5%) complications occurred, which included three (1.4%) that were access-related, nine (4.2%) intraoperative, and four (1.9%) postoperative complications. Only one complication, a liver laceration on initial trocar insertion, occurred in the group undergoing a laparoscopic simple nephrectomy, but this group had the highest rate of elective conversion (12.7%) due to lack of progression (seven of the eight elective conversions).

Gill *et al.* performed a multi-institutional review of 185 patients who underwent a laparoscopic nephrectomy, 153 of which were for benign disease [137]. Complications were threefold higher among patients undergoing radical (34%) versus a simple nephrectomy (12%). Access-related complications occurred in 2%, including one abdominal wall lesion, one trocar injury to a hydronephrotic kidney, and one hernia at a port site. Intraoperative complications included an ipsilateral pneumothorax attributed to transpleural insertion of a secondary port requiring a chest tube. Another patient suffered a splenic laceration which appeared to resolve with direct pressure, but ultimately led to a postoperative bleed and need for an open splenectomy. Other authors have successfully utilized a fibrin sealant to achieve adequate hemostasis laparoscopically when splenic laceration occurs [138]. Three patients (2%) developed a postoperative ileus, two (1.3%) cardiovascular complications, two (1.3%) urinary retention, and two (1.3%) neurologic complications. The incidence of elective conversion during laparoscopic simple nephrectomy was 3.3% with no emergent conversions.

Dissection and securing of the hilar vessels is the step related to the greatest number of "crash" conversions due to uncontrollable hemorrhage. In the series by Siqueira *et al.* all five emergency conversions, three during live donor and two during radical laparoscopic nephrectomy, occurred while dissecting and/or securing the hilar vessels or their branches. Two of these episodes resulted from a misfired or misplaced Endo-GIA stapler. Similarly, Gill *et al.*'s series reported emergency conversions for three vascular injuries, all within the laparoscopic radical nephrectomy group and none in the simple nephrectomy group [137]. One of these vascular injuries occurred as a result of a malfunction of the Endo-GIA stapler. Malfunctions during securing the hilar vessels with the Endo-GIA stapler have been reported with an incidence of 1.7%, with 50% resulting from misplacement over previously placed clips [90]. As a result of such occurrences, several authors advocate use of devices such as the LigaSure (Valley Labs, Boulder, CO, USA) [90], bipolar coagulation [139], or the Harmonic scalpel to secure the branches of the main renal vein to prevent incorporation of clips within the Endo-GIA stapler.

In a review of 2407 laparoscopic cases in urology, Fahlenkamp *et al.* demonstrated a 0.8% incidence of adjacent organ perforation [131]. They also noted a 3:1 ratio for the incidence of visceral injury during the transperitoneal versus the retroperitoneal approach, respectively [131]. In Siqueria *et al.*'s series of 213 laparoscopic nephrectomies, visceral injuries included two (0.9%) liver and one (0.5%) splenic injury [63]. Bowel injury occurred in two patients (0.9%), which is similar to the 0.8% incidence of bowel complications reported by Bishoff *et al.* in a group of 915 patients who underwent assorted laparoscopic urologic procedures [140]. Unfortunately, 70% of laparoscopic bowel injuries are not recognized intraoperatively and present with an unusual constellation of signs and symptoms unique to laparoscopic-associated perforations. These include disproportionate single trocar site pain, abdominal distention, diarrhea, and leukopenia followed rapidly by cardiopulmonary collapse [140].

Heminephrectomy

Complete duplication of the collecting system is found in one of 125 individuals [3]. The primary indications for surgical intervention include an ectopic ureter associated with a poorly functioning dysplastic upper pole moiety or an upper pole moiety with chronic obstruction and resultant poor function. Destruction and hydronephrosis of the lower pole system can also result from reflux nephropathy or a UPJO [5]. Recurrent infections, flank or abdominal pain, and incontinence may also be present [4]. Surgical intervention includes removal of the diseased moiety as well as all or a portion of the associated ureter. The laparoscopic approach to upper pole heminephrectomy was first described by Jordan *et al.* in 1993 [141]. This has since become an increasingly popular technique for the treatment of patients with this condition. Both the transperitoneal and retroperitoneal approaches have been described [5, 141–144], although most authors seem to favor the transperitoneal exposure due to the more familiar orientation of the hilum and improved working space [142].

Instrumentation

The instrumentation required is listed in Table 81.6.

Table 81.6 Instrumentation for heminephrectomy (University of Wisconsin, Madison).

Standard cystoscopic pan (*optional*)
0.035-inch floppy-tipped wire (*optional*)
6F open-ended catheter (*optional*)
Ampule of methylene blue (*optional*)
Four nonbladed trocars: two 5 mm and two 10/12 mm (with reducers)
Two 10-mm laparoscopes: one 0° and one 30°
Two 5-mm laparoscopes: one 0° and one 30° (available in the room)
One 14G Veress needle
One 10/12-mm blunt-tipped cannula (available in the room)
One trocar-mounted balloon dilation device (Origin Medsystems, Santa Clara, CA, ISA) – *retroperitoneal*
One 10/12-mm visual introducing cannula
One 5-mm curved electrocautery scissors
One 5-mm curved Maryland dissector
One 5-mm curved Harmonic scalpel and generator
One 10-mm locking Babcock
One 5-mm dolphin-nosed grasper
One 10-mm right-angled dissector
One 5-mm toothed locking grasper
One 5-mm electrocautery hook
Two 5-mm laparoscopic needle drivers (available in the room)
One 5-mm laparoscopic hand-piece for the argon beam coagulator and generator (available in the room)
One 5-mm diamond flex triangle retractor (Genzyme, Tucker, GA, USA) (available in the room)
One 10-mm PEER retractor (Jarit, Hawthorne, NY, USA)
One Martin arm (available in the room)
One 11-mm multiload clip applier (available in the room)
One 5-mm irrigator–aspirator
One grasping needle port closure device
One smoke evacuator valve (Plume-Away: Stryker Endoscopy, San Jose, CA, USA) (*optional*)
15F round Davol drain
One No. 15 blade scalpel and handle
Two fine-toothed pickups
One tonsil clamp
Two S-retractors
Three 0-Vicryl ties
Four 4-0 absorbable suture on a cutting needle
¼-inch steri-strips
Benzoin
Open nephrectomy surgical pan

Steps of the procedure

Step 1: Placement of an ureteral catheter

Some authors favor initial cystoscopic insertion of a ureteral catheter into the ureter draining the nondiseased moiety prior to performing the laparoscopic part of the procedure [141, 143]. Others do not believe this is a necessary step of the operation as the two ureters are often easy to differentiate at the time of laparoscopy [5]. The catheter does, however, aid in the identification of the normal ureter while dissecting out the dilated ureter draining the diseased moiety. It also allows injection of indigo carmine after excising the parenchyma of the upper or lower pole to help in the intraoperative identification of any inadvertent injuries to the normal collecting system of the remaining moiety. Recognition of this occurrence is important as it can usually be repaired laparoscopically and further complications can be avoided by placement of a drain with or without a stent.

For insertion of an external ureteral catheter, the patient is placed in the dorsal lithotomy position and a rigid or flexible cystoscope is utilized to introduce a 0.035-inch floppy-tipped wire under fluoroscopic control up the ureter of interest. A 6F open-ended catheter is then passed over the wire into the intrarenal collecting system. The wire is removed and contrast injected to confirm accurate positioning. The Foley catheter is inserted and the open-ended catheter is then secured to the Foley catheter using ½-inch steri-strips and benzoin or several silk ties. A piece of intravenous line extension tubing is connected to the open-ended catheter and attached to a three-way stopcock on which a 60 mL syringe filled with methylene blue-colored saline (one ampule of methylene blue to 250 mL of sterile saline) is mounted. This allows easy access for injection during the laparoscopic procedure. A ureteral drainage bag is attached to the remaining port on the stopcock. The patient is then positioned for laparoscopic renal surgery as outlined for simple nephrectomy.

Step 2: Creation of the pneumoperitoneum and initial entry access

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach.

Step 3: Placement of secondary port sites

This step is identical to that outlined for the laparoscopic nephrectomy utilizing either a transperitoneal or retroperitoneal approach.

Step 4: Exposure of the retroperitoneum

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach. Mobilization allowing unobstructed access to the hilar structures is critical as dissection and securing of the upper pole blood supply is necessary, as is the ability to pass the transected ureter behind the renal artery and vein as described below for an upper pole heminephrectomy. Deep hilar visualization and identification of these structures is also important when resecting the lower pole system, although passage of the resected collecting system behind the vessels is not necessary [5].

Step 5: Identification and dissection of the upper or lower pole and ureter

The dilated upper or lower pole ureter is usually readily identifiable as a medial tortuous tubular structure, which may be intimately attached to the ureter draining the normal moiety. This latter structure can usually be differentiated by gently drawing an instrument across the surface of the suspected location of the ureter and feeling the resistive catch as it passes over the underlying stent. The two ureters can be intimately attached and the proximal aspect of the dilated system is dissected out with care taken not to injure the wall or vasculature supplying the normal system. Dissection and exposure of the hilar vessels is identical to that described for nephrectomy. In this procedure it is not necessary to transect the main renal vessels but to mobilize them as they cross anterior to the upper pole collecting system, and to identify and dissect out the branches supplying the upper or lower pole moiety.

Complete mobilization is facilitated by performing the dissection prior to transection of the ureter as distention of the diseased moiety often helps to define the correct plane. This dissection should continue until a right-angled clamp can be passed freely behind the vessels for an upper pole heminephrectomy. Gerota's fat is usually attenuated overlying the hydronephrotic moiety. The fascia is incised and Gerota's fat is split over the extent of the diseased segment. The Harmonic scalpel is utilized to separate the adrenal gland from the upper pole system when performing an upper pole heminephrectomy. Complete mobilization of the affected moiety to the edge of the normal pole parenchyma should be performed to facilitate eventual removal of the diseased portion of the kidney.

Step 6: Division of the ureter and vasculature of the involved moiety

The ureter is then transected at the point where it can be easily separated from the normal ureter to prevent inadvertent injury to this structure. If the diseased ureter is associated with an obstructing ureterocele or an intermittently obstructing ectopic ureter which passes through the region of the bladder neck, the proximal end can be left open and all contained urine aspirated [142]. This allows for collapse of the remaining ureteral segment and prevents the establishment of a closed chamber of stagnant urine, which can lead to infection of the distal ureteral remnant. If reflux is present, most advocate removal of the involved ureter as distal as possible, leaving a strip of ureter attached to the normal ureter if necessary to prevent injury. The distal stump is then ligated or clipped adjacent to the bladder [5, 141]. Janetschek *et al.* advocate performing the distal ureteral dissection first prior to any renal manipulation [5]. Their rationale is that the likelihood of conversion is greatest during the renal part of the surgery and if an open flank incision is required after laparoscopic securing of the distal ureter, this approach saves the patient a possible second incision for the ureterectomy [5].

Once the ureter is transected, if the upper pole moiety is involved, the lowest portion of the exposed pelvis and lower ureter is grasped from above and is pulled up from behind the vessels. Additional connections between the hilar vessels and a portion of the pelvis may remain and are divided. If the lower pole is being removed, the hilar-based medial margin of the hydronephrotic moiety is identified and may lie close to the main renal vasculature.

Two 11-mm titanium clips or Weck interlocking clips are placed both proximally and distally on the arterial branches arising from the main renal artery or separately from the aorta to supply the involved moiety, and are dissected out as outlined above. The branches are then transected. Venous branches less than 4 mm in diameter can usually be secured using the Harmonic scalpel alone or with clips placed on the stay side to ensure adequate hemostasis. An Endo-GIA stapler can also be utilized to secure and divide more substantial polar vessels.

Step 7: Excision of the hydronephrotic remnant

The diseased remnant can usually be identified visually by its darkened poorly perfused appearance following transection of the polar vessels. It can also be delineated by palpation with the laparoscopic instruments, which reveals a more ballotable yielding character relative to the firmer quality of the normal renal parenchyma. The ureter and attached pelvis can be elevated and the moiety entered at the lateral juncture of the two poles away from the hilar structures. The Harmonic shears are ideal for removing the tissue of the diseased pole and providing adequate hemostasis. The edge of the resection is elevated and gently extended circumferentially, palpating opposite the planned line of incision to make certain normal parenchyma is appreciated at this level. Other devices such as the paddle cautery and argon beam coagulator can also be utilized to assist with hemostasis. On occasion, bleeding from the cut margin may be vigorous and unresponsive to the above noted measures. An absorbable suture on an SH needle may be introduced to place a figure-of-eight or short running suture to secure areas of bleeding. Knots are tied intracorporeally or, alternatively, the ends of the suture can be secured using Lapra-Tys (Ethicon Endo-Surgery),which are small absorbable Vicryl securing clips placed using a specially designed applier. Another alternative for removing the tissue and obtaining simultaneous hemostasis is to use the LigaSure (Valley Lab) bipolar vessel sealer for performing the resection of the hydronephrotic parenchyma in what has been reported to be a “bloodless resection” [145]. Others have described the use of the Endo-GIA stapler, which can be fired sequentially around the line of demarcation between the two poles or used to secure and divide the upper pole in a single firing of the Endo-GIA stapler [146]. The obvious potential complication with this latter approach is the creation of a small isolated chamber of urine with the potential for infection, although this apparently did not occur in the two renal units in which this method was utilized [146].

Step 8: Inspection for injury to the normal collecting system and drain placement

Once the specimen has been completely excised, it is placed above the spleen on the left or the liver on the right while further inspection and hemostasis is obtained. A member of the circulating personnel is then asked to use the previously assembled methylene blue irrigation set-up to inject blue-tinged saline into the collecting system [143]. Careful inspection of the bed of the resection site is performed laparoscopically to evaluate for any areas of normal collecting system injury. Any areas of leakage are closed using intracorporeal suturing and knot-tying or placement of the Lapra-Tys to secure the suture ends as outlined above. Small violations of the collecting system in regions where the surrounding tissue is insubstantial can be managed effectively by use of gel foam soaked in fibrin glue products [147, 148]. This requires that low pressures are maintained within the collecting system, which can be facilitated by converting the open-ended catheter to an indwelling double pigtail stent at the end of the procedure.

Step 9: Entrapment and removal of the specimen and drain placement

Once final inspection has been performed under both high and low insufflation pressures and hemostasis is deemed adequate, the Carter–Thomason closure device is utilized to place a fascial closure stitch at all of the 10/12-mm port sites. If the amount of resected tissue is small, it may be possible to deliver it through one of the 10/12-mm port sites. For larger specimens, a ring-attached entrapment bag (e.g. EndoCatch I) can be utilized. The entrapment device is inserted through the lower quadrant 10/12-mm port site. An instrument is then passed via the epigastric/subcostal port and utilized to grasp the specimen to deliver it into the sac. The entrapment sac is then closed and drawn out through the port and the ring is detached. The port is removed and the bag with contained specimen is removed. If the bagged specimen is too large to fit through the established port incision, it is drawn up tight against the abdominal wall and judicious enlargement of the skin and fascial incisions is performed to allow delivery of the specimen. S-retractors are inserted to provide adequate exposure of the fascia once the skin incision is enlarged. A right-angled clamp can be inserted carefully at the corner of the incision with the backside of the right angle used to protect the bag. The electrocautery or Metzenbaum scissors are utilized to enlarge the incision, with great care taken not to incise or rupture the entrapment bag. The sac can be gently rocked back and forth to deliver it from the incision, while maintaining visual monitoring of the bag to ensure that it does not rupture and that advancement of the neck of the bag correlates with progression within and not simply stretching.

Some authors advocate placement of a postoperative drain [141. 143], while others do not [5, 142]. The perforated end of a 15F round Davol drain, with the spike removed and a clamp placed on the opposite end, can be advanced through the lateral-most 5-mm port and positioned in the retroperitoneum. The 5-mm port is removed and the drain is secured to the skin using a 3-0 Nylon suture.

Step 10: Exiting the abdomen, port closure, and ureteral catheter management

Once the specimen is delivered, the insufflation is turned off, the S-retractors are reinserted, and the previously placed full-thickness fascial closure stitch is placed on traction to facilitate placement of several additional closure stitches. A 0-Vicryl suture mounted on a UR-6 needle works well for this purpose. The pneumoperitoneum is then re-established and the organ extraction site reinspected. Provided the closure is adequate and no intraperitoneal structures are incorporated, the remainder of the port closure and exiting the abdomen process is identical to that previously described for laparoscopic nephrectomy.

If no collecting system injury to the normal moiety is demonstrated, the ureteral catheter may be removed at the end of the procedure [141] or left in place until the following day if dissection around the normal ureter was extensive or the orifice noted to be tight on cannulation. Male patients can be repositioned supine and female patients frog-legged to allow fluoroscopic exchange of the stent using a metal-tipped pusher when a collecting system injury is identified and repaired. The Benson 0.035-inch wire is inserted into the external ureteral catheter after its securing steri-strips or sutures are removed. The access catheter is removed and an appropriate sized stent is inserted, followed by a metal-tipped pusher, which is then advanced until the radio-opaque band is positioned at the level of the inferior edge of the pubic symphysis under fluoroscopic guidance. The wire is removed and pigtail formation in the renal pelvis and bladder confirmed.

Postoperative care

The postoperative care following laparoscopic heminephrectomy is identical to that for nephrectomy, with the only noteworthy exception being management of the external stent. If an external stent was placed at the beginning of the operative procedure and no obvious collecting system injury to the normal moiety was demonstrated, it may be removed at the end of the operation or the next day. If a collecting system injury was demonstrated and repaired intraoperatively, the catheter can be exchanged for a double-pigtail stent using a metal-tipped pusher under fluoroscopy at the end of the laparoscopic part of the operation. If a stent is inserted it is usually left in place for 1–2 weeks to allow adequate closure and healing of the collecting system repair.

If a drain was placed, output is monitored until it is less than 30 mL on two consecutive shifts following removal of the Foley catheter on postoperative day 1. If the drain output remains elevated, a drain fluid creatinine level should be checked. The patient can be sent out with the drain in place until outputs decline if fluid creatinine is markedly elevated above the serum level. Large outputs that persist beyond 1 week are usually a result of a substantial injury to the normal collecting system that was unrecognized or inadequately repaired, or it may be due to persistent production of urine from a retained portion of the resected moiety [149]. A retrograde pyelogram into the normal ipsilateral ureter will differentiate between these two clinical scenarios by demonstrating a leak in the case of an injury and no leakage if urine is being produced by retained parenchyma. Confirmation and management of this scenario can be made by selective angiography to demonstrate residual perfused parenchyma of the resected pole, which can then be embolized [149]. An alternative management option would be a repeat laparoscopic or an open exploration and repair.

Results

The first case of laparoscopic heminephrectomy for ureteral ectopia was reported by Jordan *et al.* in 1993 [141]. Janetschek *et al.* performed 14 laparoscopic heminephrectomies in 14 patients with a mean age of 5.4 years, all via a transperitoneal approach [5]. An upper pole heminephrectomy was performed in five children with an associated refluxing ectopic megaureter and two with an obstructive ectopic megaureter. Five patients had nonfunctioning hydronephrotic lower poles secondary to reflux nephropathy and two a nonfunctioning upper pole due to an obstructing ureterocele. The average operative time was 222 min in 12 cases undergoing heminephrectomy alone and 427 min in two cases combined with a Pfannenstiel incision through which an ureterocelectomy and reimplantation of the lower pole ureter was performed [5]. In this series, blood loss was minimal (10–30 mL) and the mean length of hospital stay was 4.4 days in the 12 patients undergoing laparoscopy alone and 7–8 days in the two patients who also underwent a reimplantation. This surprisingly long stay was thought to be a reflection of differing European standards for discharge. There were no significant intraoperative or postoperative complications reported.

More recently, Horowitz *et al.* reported their series of 14 laparoscopic upper pole heminephrectomies in 13 patients with a mean age of 3.8 years [142]. Twelve were associated with an ectopic ureter (two refluxing) and two with ureteroceles. All procedures were performed via a transperitoneal approach. Their mean operative time was 100 min for the unilateral procedures and 125 min for the bilateral procedures. The mean estimated blood loss was less than 30 mL with a length of hospital stay of 2.6 days. No major intraoperative or postoperative complications were reported. Wang *et al.* reported their series of four patients undergoing laparoscopic upper pole heminephrectomy for a poorly functioning upper pole segment associated with an ectopic ureter [149]. One patient developed a urinary fistula due to persistence of a small amount of functioning upper pole parenchyma, which was identified on superselective angiography and treated successfully with embolization.

Complications

All of the complications reported above for laparoscopic nephrectomy are possible following laparoscopic heminephrectomy. Although hilar dissection is required, as well as securing of the upper pole vasculature, major intraoperative or postoperative hemorrhage did not occur in any of the series mentioned above [5, 141, 142, 149]. Urinary leakage due to a lower pole collecting system injury was not reported in these series, although Wang *et al.* presented a case of persistent urine drainage from a retained portion of upper pole parenchyma that was confirmed on super-selective angiography and successfully embolized [149].

Cyst ablation

The goal of laparoscopic cyst ablation for patients with ADPKD, large solitary or peripelvic cysts is relief of symptoms generated by the compressive effects of the cyst. These cysts often take up significant amounts of the retroperitoneal space or are located medially within the hilum, making a transperitoneal exposure ideal for their management. A retroperitoneal approach to posterior-based cysts has also been described [150].

Instrumentation

The instrumentation required is listed in Table 81.7.

Steps of the procedure

Step 1: Placement of a ureteral catheter or administration of indigo carmine

Decortication of renal cysts that arise in, or extend deep into, a peripelvic location run the risk of entry into the collecting system. Recognition of this occurrence is important as it can usually be repaired laparoscopically and further complications avoided by placement of a drain with or without a stent. Two methods can be utilized to identify entry into the collecting system; one requires cystoscopic placement of a ureteral catheter at the beginning of the operation and repositioning, the other involves simple administration of indigo carmine prior to insufflation. If an external ureteral catheter technique is desired, a cystoscopic insertion and methylene blue irrigation system is performed identical to that described for laparoscopic heminephrectomy. The patient is then positioned for laparoscopic renal surgery as outlined for simple nephrectomy.

In the alternative technique, due to the relative oliguria that occurs during laparoscopic procedures, the indigo carmine will remain present within the collecting system for the duration of the procedure. Aspiration of the cyst with examination of the aspirated fluid for the presence of blue discoloration can be utilized to determine if the aspirated structure is a portion of the collecting system prior to decortication [151]. Compression of the renal pelvis with release of blue-tinged fluid after decortication confirms an injury to the collecting system and also helps to define its location. We prefer this method for peripelvic cyst decortication due to the thin

Table 81.7 Instrumentation required for cyst ablation (University of Wisconsin, Madison).

Standard rigid or flexible cystoscopic pan (*optional: peripelvic cyst*)
0.035-inch floppy-tipped wire (*optional: peripelvic cyst*)
6F open-ended catheter (*optional: peripelvic cyst*)
Ampule of indigo carmine (*optional: peripelvic cyst*)
Ampule of methylene blue (*optional: peripelvic cyst*)
Four non-bladed trocars: • Three 5 mm and one 10/12 mm (with reducer) – no ultrasound anticipated • Two 5 mm and two 10/12 mm (with reducers) – ultrasound anticipated
Two 10-mm laparoscopes: one 0° and one 30°
Two 5 mm laparoscopes: one 0° and one 30° (available in the room)
One 14G Veress needle
One 10/12-mm blunt-tipped cannula (available in the room)
One trocar-mounted balloon dilation device (Origin Medsystems, Menlo Park, CA, USA) – *retroperitoneal*
One 10/12-mm visual introducing cannula
One 5-mm curved electrocautery scissors
One 5-mm curved Maryland dissector
One 5-mm curved Harmonic scalpel and generator
One 10-mm locking Babcock
One 5-mm dolphin-nosed grasper
One 10-mm right-angled dissector
One 5-mm toothed locking grasper
One 5-mm electrocautery hook
Two 5-mm laparoscopic needle drivers (available in the room)
One 5-mm laparoscopic hand-piece for the Argon beam coagulator and generator (available in the room)
One 5-mm diamond flex triangle retractor (Genzyme, Tucker, GA, USA) (available in the room)
One 10-mm PEER retractor (Jarit, Hawthorne, NY, USA)
One Martin arm (available in the room)
One 11-mm multiload clip applier (available in the room)
One 5-mm irrigator–aspirator
One 10-mm laparoscopic biopsy forceps (Snowden-Pencer Inc., Tucker, GA, USA)
One 5-mm laparoscopic injecting needle
One 10-mm deflectable laparoscopic ultrasound probe (Tetrad, Tetrad Corp., Englewood, CO, USA)
One grasping needle port closure device
One smoke evacuator valve (Plume-Away: Stryker Endoscopy, San Jose, CA) (*optional*)
15F round Davol drain
One No. 15 blade scalpel and handle
Two fine-toothed pickups
One Tonsil clamp
Two S-retractors
Three 0-Vicryl ties
Four 4-0 absorbable suture on a cutting needle
¼-inch steri-strips
Benzoin
Open nephrectomy surgical pan

layer of separation between the collecting system and the base of the cyst that can be perforated during wire manipulations and catheter insertion (Figure 81.13). In addition, this latter technique obviates the need for repositioning of the patient, thus reducing overall operative times.

Step 2: Creation of the pneumoperitoneum and initial entry access

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach.

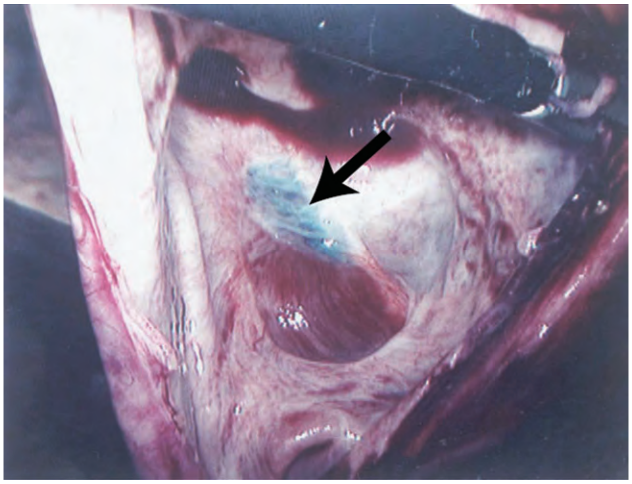

Figure 81.13 Collecting system identification during laparoscopic cyst decortication for a multichambered cyst with deep hilar extension. An ampule of indigo carmine was administered intravenously by the anesthesiologist prior to creation of the pneumoperitoneum. Note the blue-tinged urine that can be seen through the thin wall of the base of the cyst (arrow), yet no urine leakage is identified.

Step 3: Secondary port placement

There are no significant alterations to the secondary port placements as described for laparoscopic nephrectomy. Although an Endo-GIA stapler is not necessary for this operation, we maintain the left lower quadrant 10/12-mm port to use for the 10-mm lens and for removal of cyst wall specimens. Liver elevation is almost always necessary for right-sided procedures due to the cephalad extent or multiplicity of lesions requiring the lateral port as described for right-sided nephrectomies.

Secondary ports for the retroperitoneal approach are identical to those described for nephrectomy. If intraoperative ultrasound is anticipated, the 10/12-mm working port used to introduce the Endo-GIA stapler during nephrectomy can be utilized to insert the deflectable laparoscopic ultrasound probe.

Step 4: Exposure of the retroperitoneum

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach, as the majority of cysts requiring decortication are large or multiple and require access to all areas of the renal surface.

Step 5: Identification and exposure of cyst surface

Complete mobilization of the surface of the cyst wall from surrounding structures is easier to perform prior to decompression of the cyst unless exposure is limited due to its expanse. This is especially true for a large upper pole cyst on the right side secondary to overlap of the liver edge (see Figure 81.2A). Identification of a peripelvic or primarily intraparenchymal cyst can be difficult, especially in male patients with a thickened and adherent Gerota's fat layer. In such patients, use of a deflectable ultrasound probe can help to facilitate locating the margins of the cyst and guide the unroofing process. This may also prove helpful in identifying deeper parenchymal cysts during extensive decortications performed for ADPKD, or assessing wall nodularity within indeterminate cysts. Intraoperative ultrasound requires insertion via the 10/12-mm port in the left lower quadrant and moving the laparoscope to the periumbilical port site, which may require switching to a 5-mm lens if a 5-mm port was placed at this location.

Once the cyst has been exposed, confirmation that there is no connection with the collecting system should be established for a peripelvic or any cyst that extends deep along portions of the collecting system. This can be determined by puncture and aspiration using a laparoscopic needle inserted via the 5-mm port when indigo carmine was administered prior to insufflation or following a retrograde injection of methylene blue if a preoperative ureteral catheter was placed. The aspirated fluid can be placed on a clean surgical gauze to facilitate identification of a ring of blue staining when visual inspection of the syringe is equivocal secondary to pigment contained within the cysts. If concern exists regarding the possibility of malignancy, the aspirated cyst fluid can be sent for cytopathologic assessment.

It is important to make every effort to aspirate as much of the released material as possible from pigmented cysts associated with ADPKD since peritoneal contact with this material has been shown to result in a chemical peritonitis (Figure 81.14) [152]. If spillage occurs, contact areas are repeatedly irrigated using the irrigator–aspirator. The postoperative clinical course of these patients can be difficult to differentiate from patients suffering an unrecognized bowel injury and can also result in a profound ileus.

Step 6: Cyst unroofing, biopsy, specimen extraction

The Harmonic scalpel is the ideal device for unroofing large simple cysts, as well as multiple cysts associated with ADPKD because it limits bleeding from the cut edge of the cysts, yet minimizes collateral damage to structures such as the collecting system [129]. It is safest to begin opening the cyst at its thinnest point, which typically is found far from the edges. This is appreciated as a translucent appearing area that is often darker than surrounding regions of the kidney due to the underlying cavity. A laparoscopic aspirating needle can be inserted in this area as described above. Incision of the

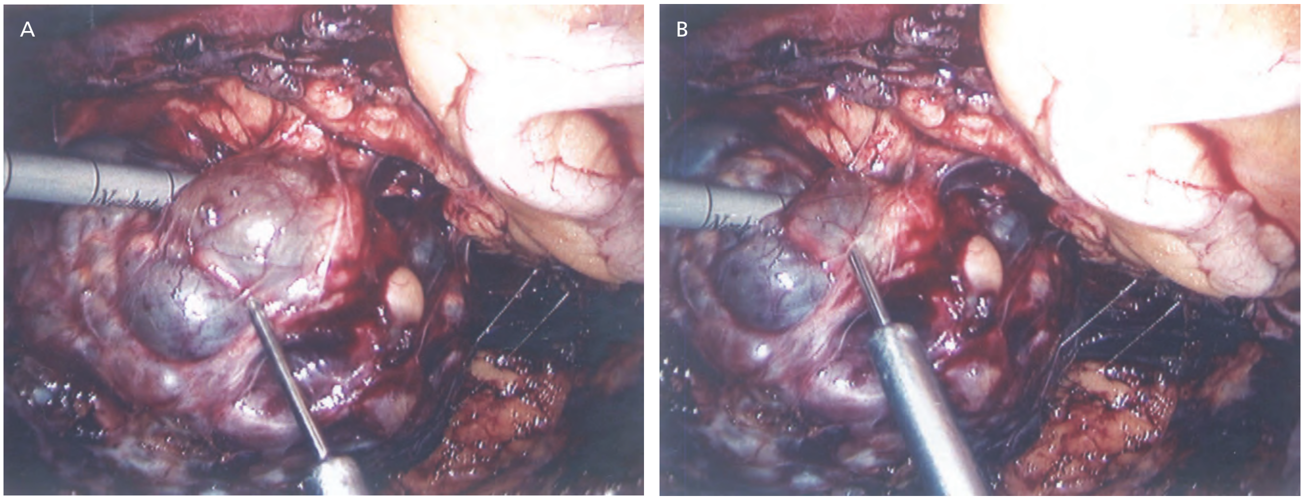

Figure 81.14 Laparoscopic cyst decortication in a patient with autosomal dominant polycystic kidney disease and numerous pigmented cysts. (A) To prevent postdecortication peritonitis syndrome induced by release of pigmented fluids into the peritoneal cavity, needle puncture of each pigmented cyst and (B) aspiration of its contents should be performed prior to unroofing with the Harmonic shears and thorough irrigation.

cyst wall is continued down to its border with normal parenchyma or collecting system, and the entire margin is circumferentially excised. This can be removed in sequential strips if a question exists regarding what is parenchyma and what is cyst wall. More vigorous edge bleeding often implies entry into normal parenchyma and can usually be controlled using the Harmonic device, bipolar electrocautery, pressure with a sheet of Surgicel, or the argon beam coagulator. On rare occasion, a figure-of-eight suture or a short interlocking running stitch along the edge may be required for hemostasis.

If a concern exists regarding the possibility of malignancy, as occurs with decortication of complex cystic lesions, the cyst fluid should be completely aspirated and sent for cytology. The excised cyst walls should be sent for pathologic inspection along with a biopsy of the base of the cyst. The cyst base biopsies are taken from regions that are not immediately adjacent to the collecting system. If a region of obvious thickening or nodularity is noted, specimens should be taken from these regions. Careful scrutiny of preoperative imaging studies can help locate areas of concern within the base of the cyst and guide sites for biopsy.

Smaller cyst wall and biopsy specimens can be removed directly via 10/12-mm ports. Larger cyst wall specimens for which there is no concern for malignancy can be cut into strips and removed through the 10/12-mm port. Alternatively, an EndoCatch I or II bag can be utilized to bag and remove the specimen. The EndoCatch I bag can be inserted via a 10/12-mm port, but requires ultimate removal of the port for specimen extraction. An EndoCatch II bag can be utilized when the specimen(s) is especially large, but requires initial removal of the port and insertion via the port incision. We prefer to perform specimen extraction via the lower quadrant port site as it is the most elevated in the flank position, preventing contact with bowel or deep intraperitoneal displacement of the specimen should a perforation of the bag occur. Morcellation can be performed as outlined for simple nephrectomy.

Decortication of all visible superficial and deeper cysts as well as final ultrasound inspection with a 10-mHz deflectable Tetrad ultrasound unit (Tetrad Corp, Englewood, CO, USA) to help identify any other previously unrecognized cysts within several millimeters of accessible surfaces has been advocated by several authors [8]. These additional cysts are also marsupialized, and the average number of cysts decorticated using this approach was 220 cysts per procedure in one review [8]. Due to the degree of mobilization and the resultant volume reduction following the procedure, some authors performed a postdecortication nephropexy in 77% of their patients using a 0 Polyglactin suture passed through the posterior abdominal wall fascia and capsule of the kidney, and secured at each end with a Lapra-Ty [8, 153]. This helps prevent hypermobility and torsion of the decompressed kidney on its hilar structures.

Step 7: Final inspection, exiting the abdomen, and port closure

Final inspection for hemostasis following cyst decortication is identical to that previously described for laparoscopic nephrectomy. In addition, the areas of decortication and base biopsies should also be carefully inspected for evidence of urine leakage. If an externalized ureteral catheter was utilized, the circulating nursing staff or assistant can inject dilute methylene blue to help identify any leaks. If injected indigo carmine was utilized, gentle compression of the renal pelvis will assist in identifying any injury. An attempt at suture closure should be performed for all substantial collecting system lacerations utilizing a 4-0 Vicryl or Polydioxanone suture. Smaller injuries involving the calyces will often seal with stent drainage alone. Closure sutures are placed at each of the 10/12-mm port sites using the Carter–Thomason device. If a collecting system injury occurs, a 15F round Davol drain with the spike removed can be inserted via the 5-mm lateral port site. A clamp is secured to its end to prevent leakage of the CO_2 as it is fed into the abdomen and positioned in the retroperitoneum. The 5-mm port is then removed and the drain is secured to the skin using a 3-0 Nylon suture. The abdomen is desufflated, fascial entry sites are secured, and the peritoneal cavity is exited as previously described for laparoscopic nephrectomy.

If a collecting system repair was required, a ureteral catheter can be inserted at the end of the procedure. A simple stent exchange can be performed under fluoroscopy if an open-ended catheter was utilized without repositioning by utilizing a 0.035-inch floppy-tipped wire, a metal-tipped pusher, and an appropriate size stent. In this approach the stent is inserted, followed by the metal-tipped pusher, which is advanced to the inferior edge of the pubic symphysis, and the wire is removed under fluoroscopy, confirming proper position of the proximal and distal pigtails. If an external catheter was not utilized, the patient can be repositioned in the dorsal lithotomy, reprepped and draped, and a wire and subsequent stent introduced via the cystoscope in standard fashion. A Foley catheter is then inserted at the end of the procedure to minimize reflux along the stent.

Postoperative care

The immediate postoperative care of patients having undergone renal cyst decortication is identical to that after laparoscopic simple nephrectomy, with the following noteworthy exceptions. If a collecting system injury occurred and a drain and stent were inserted, the Foley catheter is left in place for 24 h provided the drain output is minimal (i.e. <30 mL/8 h). The Foley catheter is removed on postoperative day 2 and the drain output is monitored. If the drain output increases markedly, the source of the fluid can be evaluated by sending it for a creatinine level. If it is significantly above the measured serum creatinine level, then a portion of the fluid is urine and the Foley catheter should be left in place or replaced if it was removed. Once the Foley catheter has been discontinued and there is no significant increase in the drain output over the next 8-h shift, the drain can be removed. Patients are usually sent home on postoperative day 2 or 3. The stent is left in place for approximately 1 week and a retrograde pyelogram can be performed at the time of removal if concern exists regarding continued leakage.

The other exception to the standard postoperative care of patients following renal cyst decortication are those patients with ADPKD and a large number of hemorrhagic cysts. These patients can have a very protracted course secondary to a chemical peritonitis from the contents of the cysts and, as a result, can require up to 50% more parenteral analgesics than patients undergoing laparoscopic removal of their entire kidney [152]. The clinical postoperative presentation of these patients can include distention, diffuse abdominal pain, fever, elevated white blood cell count, and a profound ileus. In these patients, supportive care with intravenous fluids, pain medication, and tincture of time lead to ultimate resolution, although this can significantly prolong the hospital stay.

Results

Simple symptomatic parenchymal cysts

In a review of five series totaling 74 patients with large symptomatic cysts, the radiographic success rate of laparoscopic decortication was 90% over a mean follow-up of 7 months [6]. Lifson *et al.* reported their series of five patients undergoing cyst decortication for a symptomatic large cyst, with all five remaining pain free on a mean follow-up of 33 months [154]. Roberts *et al.* reviewed their series of laparoscopic decortication of large symptomatic parenchymal cysts in 21 patients [7]. Thirteen patients in their series had a transperitoneal and eight a retroperitoneal approach with a mean operative time of 164 min, operative blood loss of 98 mL, and a hospital stay of 1.9 days. They noted a 5% recurrence rate over a mean follow-up period of 15.8 months, although only 58% of the patients in their entire series underwent follow-up imaging [7].

Peripelvic cysts

Most reported series do not clearly delineate between peripelvic and parenchymal cysts. However, Roberts *et al.* compared their series of 21 parenchymal to 11 peripelvic cysts for which a laparoscopic decortication was performed [7]. A similar distribution of approaches (seven transperitoneal, four retroperitoneal) was noted for the peripelvic operations relative as was mentioned above for parenchymal lesions. There was a statistically significant longer mean operative time (233 min) and blood loss (182 mL) noted for the peripelvic cyst decortications, which was felt to reflect the more technically challenging nature of this operation. Mean follow-up of 22.4 months did not demonstrate any evidence of recurrence. Not surprisingly, the percentage of patients with inadvertent entry into the collecting system was higher for the patients with peripelvic (18%) relative to simple parenchymal cysts (14.3%) [7]. Rubenstein *et al.* described one patient in their series of 10 laparoscopic cyst decortications with a large peripelvic cyst extending between the renal artery and vein. The cyst was decorticated and a wick of 6 x 1 cm polytetrafluoroethylene placed to help prevent reformation of the cyst [155]. This patient developed a small recurrent cyst, but remained asymptomatic at 10 months.

Hoenig *et al.* reviewed their experience of laparoscopic ablation of symptomatic peripelvic cysts in four patients [20]. Cyst size ranged from 4 to 6 cm and two patients had concomitant stone disease. Three of the four underwent a transperitoneal approach and one a retroperitoneal approach with a mean operative time of 338 min, estimated blood loss of 90 >mL, and length of stay of 2.75 days. One patient suffered a laceration of the renal pelvis, which was recognized and repaired intraoperatively. All patients had initial resolution of their preoperative pain, but one patient developed a symptomatic recurrence at 2 months requiring an open decortication. Another patient developed an asymptomatic recurrence of a 2-cm peripelvic cyst at 9 months.

Doumas *et al.* reported their series of five patients with peripelvic cysts ranging from 4.5 to 6.5 cm in size [156]. All underwent transperitoneal laparoscopic decortication with a mean operative time of 155 min and estimated blood loss of less than 150 mL. No intraoperative complications and only one minor postoperative complication (subcutaneous hematoma) occurred. All patients remained free of symptoms and radiographic evidence of obstruction at a mean follow-up of 23 months.

Indeterminate complex cystic lesions

Most surgeons advocate treating Bosniak IV (Table 81.1) lesions identical to cystic renal cancer due to the 90% risk of reported malignancy [6, 14, 15]. Controversy exists in the use of laparoscopy to evaluate and manage asymptomatic or symptomatic Bosniak II and III lesions with their associated 24% and 41% risk of malignancy. Even though completion nephrectomy can be performed when cancer is identified in resected wall segments or aspirated fluids, a case report by Meng *et al.* illustrates the possibility that laparoscopic decortication may alter the progression pattern of disease if it goes undiagnosed [16]. Their case had a symptomatic 20-cm Bosniak I lesion and underwent a laparoscopic cyst decortication. Analysis of the cyst wall demonstrated benign tissue. Seven months later the patient presented with a large renal mass involving the spleen and colon as well as liver, subcutaneous port site, lymph node, and peritoneal metastases. Pathology revealed Fuhrman grade 4 chromophil and sarcomatoid renal carcinoma [16]. The diffuse spread of disease over a relatively short period of time suggests that tumor spillage and possibly convection-related dissemination from the pneumoperitoneum likely contributed.

In contrast to this case, Santiago *et al.* reported their series of 35 patients who underwent laparoscopic assessment and management of Bosniak II and III lesions [17]. A total of five (14.3%) were discovered to harbor malignancy; four underwent immediate partial or radical nephrectomy and one a delayed partial nephrectomy. No recurrences were identified after a mean follow-up of 20.2 months. Roberts *et al.* described their series of laparoscopic management of renal cystic disease, which included eight patients with Bosniak II and III lesions [7]. One patient (12.5%) was identified on final pathology to have a small (<1 cm) focus of papillary renal cancer and underwent eventual open radical nephrectomy with excision of the trocar site used for specimen extraction. In a similar case, Lifson *et al.* discovered a small focus of papillary carcinoma in the cyst wall of a Bosniak I lesion and the patient underwent immediate open radical nephrectomy [154]. A prior negative cyst fluid aspiration cytology had been obtained on the patient and he remained free of disease recurrence at 58 months of CT scan follow-up [154].

The results of these last three series indicate that, in select patients with indeterminate cysts, laparoscopy may provide a reasonable diagnostic and therapeutic approach provided a careful inspection of the cyst base with biopsy, cytologic evaluation of aspirated fluid, and meticulous pathologic review of the resected cyst wall is performed. The finding of positive aspiration cytologies in only 14% of proven cystic malignancies [157] and the case report by Meng *et al.* [16] illustrate that accurate diagnosis at the time of laparoscopy may not be feasible and misdiagnosis may have a disastrous effect on the ultimate course of disease.

Autosomal dominant polycystic kidney disease

Symptomatic recurrence requiring repeat surgical therapy occurs more frequently following decortications performed for ADPKD, due to the multifocal, progressive nature of the disease. Subsequent treatment, including repeat laparoscopic decortication, cyst puncture with aspiration, and nephrectomy, is required in 10.3–37.5% of patients [8, 129, 154, 158]. Overall improvement in pain, bowel, or pulmonary complaints

Table 81.8 Results of laparoscopic cyst decortication in autosomal dominant polycystic kidney disease patients.

Series	Patients (proceedures)	TP/ RP	Operative time (mean, min)	Analgesia (morphine equiv, mg)	LOS (days)	EBL (mL)	Transfusion (%)	*Symptomatic success*	Follow-up (mean, months)	Repeat treatment	Complications
Lee *et al.* [8]	29 (35)	33/2	294	61.1	3.2	124	0	>50% pain reduction 73% (12 months) 52% (24 months) 81% (36 months)	32.3	10.3%	3 (8.6%) – major 7 (20%) – minor
McNally *et al.* [129]	7 (8)	8/0	–	–	3.9	<200	25	51% pain reduction (14 months)	14	14.3%	3 (37.5%) – major
Lifson *et al.* [154]	8 (11)	10/1	137	–	2.2	116	9	Pain free 87.5% (6 months) 71.4% (12 months) 66.7% (24 months) 25% (36 months)	24	37.5%	1 (9%)
Brown *et al.* [158]	8	8/0	164	–	<2	<150	–	50% (12–28 months)	12–28	37.5%	0

TP, transperitoneal; RP, retroperitoneal; LOS, length of stay; EBL, estimated blood loss.

has been defined and reported in variable fashion (Table 81.8). Lee *et al.* utilized analog pain scores to calculate the relative pain relief (RPR) value for each patient, which equaled (preoperative pain score) – (postoperative pain score)/(preoperative pain score). The RPR was calculated as 58%, 47%, and 63% at 12, 24, and 36 months, respectively. Greater than 50% reduction in pain was noted in 73%, 52%, and 81% of patients at 12, 24, and 36 months, respectively. These authors also showed significant improvements in six of eight quality of life domains 1 year following laparoscopic decortication [8].

Intrarenal ischemia from cyst growth, renal handling of sodium, inappropriate activity of the renin–angiotensin–aldosterone system, volume expansion, and increased atrial natriuretic peptide and plasma endothelin levels have been postulated to contribute to the hypertension noted in 50–70% of ADPKD patients before renal function is impaired [28]. Lee *et al.* evaluated the impact of laparoscopic decortication on hypertension in their patients using the antihypertensive therapeutic index (ATI), defined as [(dose of blood pressure medication 1/maximum dose 1) + (dose medication 2/maximum dose 2) + etc.] [8]. A total of five (23.8%) of the initial 21 patients with hypertension became normotensive following their procedure. Nine additional patients had a mean 49% improvement in their ATI; however, six patients had a mean worsening of 53%. The impact on creatinine clearance was also assessed using pre- and post-operative Cockcroft and Gault calculations of renal function, which demonstrated changes of +4%, +7%, and −2% at 1, 2, and 3 years, respectively [8].

Complications

The potential complications that can occur with cyst decortications include all of those mentioned previously for laparoscopic nephrectomy, with the exception of Endo-GIA malfunction. Complications that occur with greater frequency following decortication procedures include collecting system injury with resultant urinoma in as high as 8.5% of patients with ADPKD [8], 14.3% of simple parenchymal and 18% of peripelvic cysts [7]. Hemorrhage requiring transfusion occurred more commonly in patients undergoing decortication procedures in association with ADPKD (Table 81.8). Several of these cases were associated with the administration of heparin following concomitant insertion of a dialysis catheter [129]. The discovery of malignancy in less than 0.7% of simple cysts [15] and 12.5–14.3% of patients undergoing laparoscopic decortication for Bosniak II and III lesions [7, 17] could potentially lead to the catastrophic spread of disease, as described by Meng *et al*. [16].

Calycealectomy

The laparoscopic approach to stone-bearing calyceal diverticula is best suited to anterior-based lesions, as mentioned above under indications [159]. For this reason, we prefer a transperitoneal approach for this operation, although retroperitoneal exposure of the kidney with access and trocar distribution as described above has been described [160]. The purported advantages of the retroperitoneal approach are the lack of manipulation of the bowels, as well as the reduced potential for intraperitoneal extrusion of stone or infectious material.

Instrumentation

The instrumentation required for calycealectomy is listed in Table 81.9.

Steps of the procedure

Step 1: Placement of a ureteral catheter or administration of indigo carmine

This step is identical to that outlined above for renal cyst decortications when cysts closely approximate the collecting system.

Step 2: Creation of the pneumoperitoneum and initial entry access

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach.

Step 3: Secondary port placement

The only alterations to the secondary port placements as described for laparoscopic nephrectomy is the replacement of the periumbilical 10/12-mm port with a 5-mm port as Endo-GIA stapler insertion is not necessary. Ultimately, this will require the use of a 5-mm laparoscopic lens during placement of the stone(s) into the EndoCatch I bag and for fascial closure of the 10/12-mm port site. Depending upon the location of the diverticulum on the right, liver elevation may not be necessary, provided the lesion is located in the mid region of the kidney or the kidney sits lower in the retroperitoneum. This eliminates the need for the lower lateral port for right-sided procedures, which is used almost exclusively for liver elevation.

Secondary port placement for the retroperitoneal approach is identical to that described for nephrectomy, with the exception of replacing the 10/12-mm trocars

Table 81.9 Instrumentation for calycealectomy (University of Wisconsin, Madison).

Standard rigid or flexible cystoscopic pan
0.035-inch floppy-tipped wire
6F open-ended catheter
Ampule of indigo carmine
Ampule of methylene blue
Three nonbladed trocars – *left*; four nonbladed trocars – *right*:
• Two 5 mm and one 10/12 mm (with reducer) – *left* • Three 5 mm and one 10/12 mm (with reducer) – *right*
Two 10-mm laparoscopes: one 0° and one 30°
Two 5-mm laparoscopes: one 0° and one 30° (available in the room)
One 14G Veress needle
One 10/12-mm blunt-tipped cannula (available in the room)
One trocar-mounted balloon dilation device (Origin Medsystems, Menlo Park, CA, USA) – *retroperitoneal*
One 10/12-mm visual introducing cannula
One 5-mm curved electrocautery scissors
One 5-mm curved Maryland dissector
One 5-mm curved Harmonic scalpel and generator
One 10-mm locking Babcock
One 5-mm dolphin-nosed grasper
One 10-mm right-angled dissector
One 5-mm toothed locking grasper
One 5-mm electrocautery hook
One 5-mm laparoscopic needle drivers (available in the room)
One 5-mm tri-radiate grasping forceps
One 5-mm laparoscopic injecting needle
One 5-mm laparoscopic argon beam coagulation probe
One 10-mm PEER retractor (Jarit, Hawthorne, NY, USA)
One 11 mm multiload clip applier (available in the room)
One 5-mm irrigator–aspirator
One EndoCatch I bag (stone specimen removal)
One grasping needle port closure device
One smoke evacuator valve (Plume-Away: Stryker Endoscopy, San Jose, CA, USA) (*optional*)
One 5-mm diamond flex triangle retractor (Genzyme, Tucker, GA, USA) (available in the room – *right*)
One Martin arm (available in the room – *right*)
One No. 15 blade scalpel and handle
Two fine-toothed pickups
One tonsil clamp
Two S-retractors
Three 0-Vicryl ties
Four 4-0 absorbable suture on a cutting needle
¼-inch steri-strips
Benzoin
Open nephrectomy surgical pan

with 5-mm ports. Again, this will require the use of a 5-mm laparoscope for bagging of the stone specimen.

Step 4: Exposure of the retroperitoneum

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach, with the following exceptions. Complete splenic mobilization may not be necessary for diverticulum in the mid region of the left kidney as complete upper pole exposure is often unwarranted. Alternatively on the left, the line of Toldt can be incised around the splenic flexure, leaving the pancreas and spleen *in situ*. This usually provides adequate exposure and requires less dissection. On the right, the duodenum does not have to be kocherized unless it closely approximates the area of involved parenchyma as access to the great vessels is not necessary for this procedure.

Step 5: Renal dissection and identification of the diverticulum

A 30° 10-mm laparoscope is inserted through the 10/12-mm port in the lower quadrant for the transperitoneal approach. In the retroperitoneal approach, a 30° lens is also utilized via the 10/12-mm port off the tip of the 12th rib. The surgeon operates via the 5-mm ports utilizing the Maryland dissector held in the nondominant and the Harmonic shears in the dominant hand. If the location of the diverticulum on the right requires liver elevation for adequate exposure during the transperitoneal approach, the Diamond Flex Retractor is inserted through the lateral 5-mm port between the tip of the 12th rib and iliac crest. The retractor handle is twisted until the appropriate triangle configuration is obtained and it is then placed beneath the liver edge, elevated into position, and secured to the operating table utilizing the Martin robotic arm or an Endo-holder. Care should be exercised to prevent unnecessary pressure on the gallbladder or porta hepatis.

The kidney contained within Gerota's fascia and fat is usually easily identified by palpation of a firm structure in the retroperitoneum. The Harmonic shears are utilized to divide Gerota's fascia and fat overlying the lateral margin of the kidney, beginning at the lower pole and progressing cephalad. Frequent infections and inflammatory events may make exposure of the smooth capsular surface of the kidney difficult. The Harmonic device is ideal for performing this separation as it limits the amount of capsular oozing. The relative location of the calculus within the kidney is known as a result of the preoperative CT scan imaging confirming its regional position. The exact location is identified laparoscopically as a parenchymal indentation on the surface of the

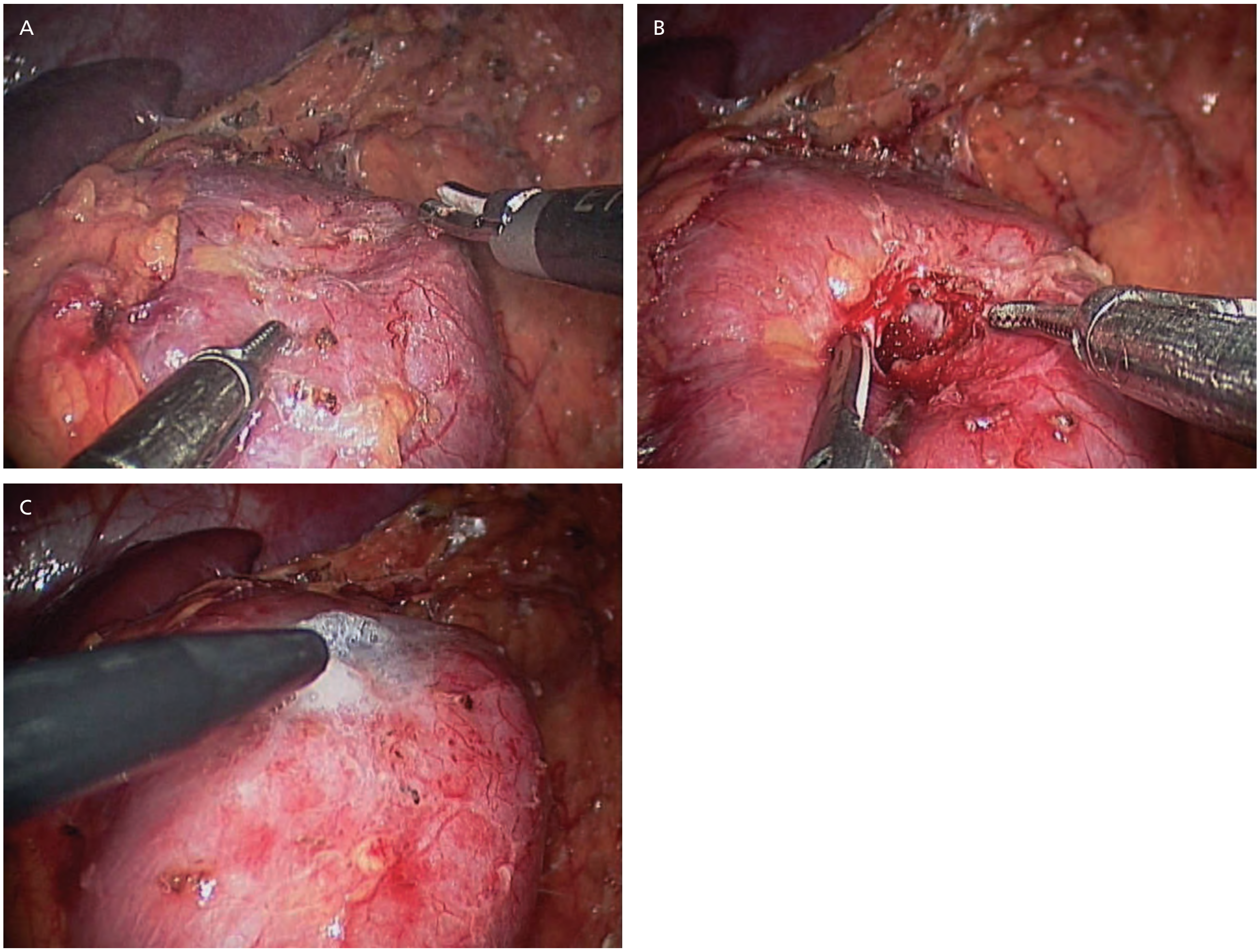

Figure 81.15 Laparoscopic calycealectomy. (A) An indentation on the surface of the renal parenchyma marks the location of the diverticulum. (B) Harmonic shears are utilized to unroof the overlying parenchyma. (C) The small ostium of the diverticulum is occluded utilizing fibrin glue products.

kidney [160] (Figure 81.15A), although this area can also appear raised relative to the surrounding parenchyma [159]. If inflammatory events have occurred within the diverticulum, the overlying fat may adhere to and fill the parenchymal depression. This can be probed with a laparoscopic aspirating needle to confirm the presence of the underlying stone as a hard area of contact feedback. Theories regarding thinning of the parenchyma in this region include a lack of induction of the metanephric blastema in this region for those who believe in congenital origins versus resultant scarring and atrophy from inflammation [36–38].

Step 6: Incision of the diverticulum and stone extraction

Regardless of the origin, the parenchyma in this region is usually thin and devoid of significant blood supply, allowing incision with the electrocautery or Harmonic shears (Figure 81.15B) without marked hemorrhage [160]. Once the overlying parenchyma has been incised, the diverticulum is irrigated gently to reveal the contained stone. The 10-mm laparoscope is exchanged for the 30º 5-mm lens, which is inserted in the subcostal region for the transperitoneal approach and in the posterior axillary line 5-mm port for the retroperitoneal approach. The EndoCatch I bag is introduced via the 10/12-mm port and the other 5-mm port is utilized to extract the stone(s) using the percutaneous three-prong graspers and to place all stone material into the entrapment sac (Figure 81.16). The drawstring is then pulled tight on the sac, the port is removed, and the drawstring clamped near the skin level. The stones within the entrapment sac are left *in situ* within the peritoneum or retroperitoneum, and the port is then reintroduced.

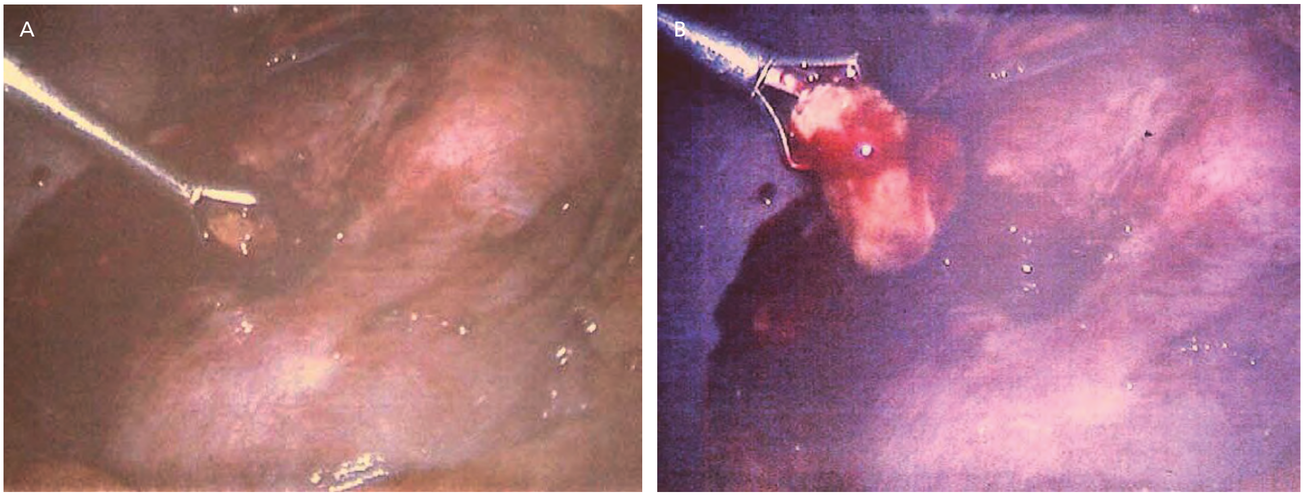

Figure 81.16 Laparoscopic calycealectomy and stone extraction. (A) The thinned area of parenchyma has been incised and the stone can be visualized as it is being engaged utilizing the three-prong percutaneous stone graspers. (B) The stone is extracted from the diverticulum and deposited into an entrapment sac.

Step 7: Diverticulum ablation and closure of collecting system

The diverticulum is inspected to find its communication with the collecting system. Identification is facilitated by injection of methylene blue via the externalized ureteral catheter or by gentle compression of the renal pelvis if preinsufflation indigo carmine was utilized instead. Both techniques result in a stream of blue-tinged urine emitting from the area of the connection. If the opening is not identified using these techniques, then it is likely extremely small and fulguration of the area alone or application of fibrin glue products (see Figure 81.15) will usually suffice to prevent leakage of urine. The 5-mm laparoscopic argon beam coagulator is ideal for complete ablation of the urothelial lining of the diverticulum, although the back of the electrocautery or Harmonic shears can also be utilized. Once the entire surface has been ablated, a 3-0 Vicryl on an RB-1 needle is inserted via the 10/12-mm port and a figure-of-eight closure suture is placed across the mouth of the diverticulum. Repeat injection of methylene blue via the externalized stent (or compression of the pelvis if intravenous indigo carmine is utilized) confirms a watertight closure.

One option when a large, gaping cavity is created that is unlikely to collapse following fulguration, is to insert a tongue of Gerota's fat into the base of the diverticulum. It is then secured with one or more sutures of 3-0 Vicryl to the wall of the diverticulum utilizing intracorporeal suturing techniques.

Step 8: Exiting the abdomen, drain placement, and port closure

The area of the dissection is inspected for hemostasis once again at low insufflation pressures and all bleeding points are cauterized. The perforated end of a 15F round Davol drain with the spike removed is inserted, via the lower quadrant port in the transperitoneal approach and the lateral-most port in the retroperitoneal approach. Placing a clamp on the back-end of the drain prevents release of the pneumoperitoneum during this maneuver. A grasper is inserted via the port used to bag the specimen and is utilized to position the drain lateral and behind the kidney to monitor for any leakage of urine. The specimen is removed under vision of the 5-mm laparoscope inserted via the remaining 5-mm port with the fascial incision enlarged if necessary. If enlargement of the fascial site is not anticipated, then the fascial closure needle can be utilized to place a closure stitch at the port site prior to insertion of the drain. The final port is removed as previously described after evacuation of the pneumoperitoneum. As with other retroperitoneal procedures, the blunt-tip trocar site is usually closed under vision while the fascial incisions of the 5-mm ports are not sutured. The skin incisions are closed as previously described.

Postoperative care

The postoperative care following laparoscopic calycealectomy is identical to that for cyst decortication. If an external stent was placed at the beginning of the operative procedure, it is removed at the end of the operation or exchanged for a double-pigtail stent using a metal-tipped pusher under fluoroscopy when closure of the ostium of the diverticulum is in question. The drain output is monitored until it is less than 30 mL on two consecutive shifts following removal of the Foley catheter on postoperative day 1. If the drain output remains elevated, a drain fluid creatinine level should be checked, and if it is markedly elevated above serum levels, the patient can either be sent out with the drain until outputs decline, or a double-pigtail stent can be inserted if large volume urine-laden drainage continues. If a stent is inserted, it is usually left in place for 1 week to allow adequate coaptation and closure of the mouth of the diverticulum.

Results

There have been limited published series on laparoscopic calyceal diverticulectomy with reported stone-free and diverticulum obliteration rates of 92–100% with short follow-up (<1 year) [159–161]. Approaches utilized in the literature are split between the transperitoneal and retroperitoneal approaches with mean operative times of approximately 130 min [160].

Complications

Any of the intraoperative or postoperative complications related to access entry, retraction, dissection, or port closure as described for simple nephrectomy are possible with laparoscopic diverticulectomy. The one exception is no risk of a major vascular event secondary to Endo-GIA stapler misadventure because no major vascular structures should require transection during this procedure. A total of three complications among five patients who underwent laparoscopic calyceal diverticulectomy have been reported in the literature. One patient had a significant hemorrhage requiring a 3-unit blood transfusion [160]. This presumably occurred at the site of incision of the diverticulum. Another had a persistent discharge from their port site for 2 months [160]. The source of this prolonged drainage was not detailed further and was said to resolve spontaneously without any described intervention. Another patient was noted to have prolonged crepitance, which was thought to be a result of using the argon beam coagulator since it persisted for 1 week, which exceeds what would be expected from rapidly absorbed CO_2 [38].

Another potential complication, not reported in the literature, which has occurred following laparoscopic diverticulectomy is a persistent urine leak or urinoma development in the flank (T.J. Moon, personal communication). This results from either inadequate suture closure of the neck of the calyceal diverticulum or inadvertent dissection into the collecting chamber at a site other than the connection. Drainage usually abates rapidly following insertion of a ureteral stent. If stent placement is unsuccessful in resolving a urinary fistula, more invasive methods extrapolated from similar scenarios following partial nephrectomy such as percutaneous drainage, tissue adhesive injection, or open exploration could be required [162, 163].

Nephropexy

In 1993, Urban *et al.* reported the first case of laparoscopic nephropexy for the treatment of clinically significant nephroptosis [164]. It has since been shown to be equally efficacious with superior postoperative pain, morbidity, and convalescence in comparison to the open approach [54]. Laparoscopic fixation of the kidney to the quadratus lumborum fascia can be accomplished via a transperitoneal or retroperitoneal exposure. We, along with other groups, advocate upper pole fixation to the cut margin of the coronary ligament of the liver, which is best accomplished via a transperitoneal exposure [165]. A retroperitoneal exposure with fixation to the quadratus fascia only has been described with the port distribution as outlined for retroperitoneal nephrectomy [166]. As previously mentioned, the majority of nephropexy procedures are performed on the right with only 10% of cases isolated to the left kidney [49, 59].

Instrumentation

The instrumentation required for nephropexy is listed in Table 81.10.

Steps of the procedure

Step 1: Creation of the pneumoperitoneum and initial entry access

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach. Care must be exercised in these cases on initial entry with the Veress needle in the lower quadrant as the kidney can be displaced into this area in some cases of extreme mobility. Usually air-planing the table slightly away from the operating surgeon will cause the kidney to roll into a more normal location.

Step 2: Secondary port placement

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach with the exception that only the periumbilical port needs to be a 10/12-mm port to

Table 81.10 Instrumentation required for nephropexy (University of Wisconsin, Madison).

Four nonbladed trocars: three 5 mm and one 10/12 mm (with reducer)
Two 10-mm laparoscopes: one 0° and one 30°
Two 5-mm laparoscopes: one 0° and one 30° (available in the room)
One 14G Veress needle
One 10/12-mm blunt-tipped cannula (available in the room)
One trocar-mounted balloon dilation device (Origin Medsystems, Menlo Park, CA, USA) – *retroperitoneal*
One 10/12-mm visual introducing cannula
One 5-mm curved electrocautery scissors
One 5-mm curved Maryland dissector
One 5-mm curved Harmonic scalpel and generator
One 10-mm locking Babcock
One 5-mm dolphin-nosed grasper
One 10-mm right-angled dissector
One 5-mm toothed locking grasper
One 5-mm electrocautery hook
One 5-mm laparoscopic needle drivers
One 5-mm laparoscopic argon beam coagulation probe
One 10-mm PEER retractor (Jarit, Hawthorne, NY, USA)
One 11-mm multiload clip applier (available in the room)
One 5-mm irrigator–aspirator
One grasping needle port closure device
One smoke evacuator valve (Plume-Away: Stryker Endoscopy, San Jose, CA, USA) (*optional*)
One 5-mm diamond flex triangle retractor (Genzyme, Tucker, GA, USA)
One Martin arm (available in the room)
One No. 15 blade scalpel and handle
Two fine-toothed pickups
One tonsil clamp
Two S-retractors
Three 0-Vicryl ties
Four 4-0 absorbable suture on a cutting needle
¼-inch steri-strips
Benzoin
Open nephrectomy surgical pan

enable insertion of the needle-mounted sutures, whereas all others can be substituted with 5-mm ports. This requires the use of a 5-mm laparoscopic lens. Alternatively, the same port sizes and configuration for laparoscopic nephrectomy can be utilized for this procedure, allowing use of the 10-mm laparoscope if desired.

Step 3: Exposure of the retroperitoneum

This step is identical to that outlined for laparoscopic nephrectomy utilizing either the transperitoneal or retroperitoneal approach. In the transperitoneal approach it is not necessary to kocherize the duodenum as access to the hilar vessels is unnecessary and this structure is widely separated from the lateral margin of the kidney. The Genzyme liver retractor is inserted via the lateral-most port and is utilized by the assistant surgeon to elevate the liver edge to expose the coronary ligament. Care should be exercised when transecting the infrahepatic peritoneal attachments to the liver to leave enough of a shelf-like edge beneath which the upper pole of the kidney can be inserted and two securing sutures to the renal capsule placed as described by Elashry *et al*. [165].

Step 4: Exposure of the renal capsule and quadratus fascia and patient positioning

Once the kidney is exposed within Gerota's fascia, it should be elevated back into its standard position as it may be found flipped into a medial or inferior location. Appropriate positioning of the kidney in the retroperitoneum is facilitated by placing the patient into a deep Trendelenburg position and air-planing the table away from the operating surgeon. The lateral and superior border of the kidney are identified, Gerota's fascia is incised over this area, and the anterior fat is peeled back from the surface of the kidney while several centimeters of the posterior layer of fat is excised to expose the capsule of the kidney. The contact region between the edge of the kidney and the retroperitoneal fat is noted and the Harmonic shears are utilized to remove all of the fat overlying this region, so the broad fascial surface of the quadratus musculature is available for suturing (see Video 81.1). The lack of intervening fat allows for better visualization during suture placement through the quadratus fascia and renal capsule, and creates better contact between the surfaces of these structures. The use of an intervening strip of Gerota's fat as a bolster over which the securing sutures are tied can result in necrosis of the fat and resultant mobility. Differing thickness of fat bolsters can also result in poor contact points, stress at the remaining sutures, tear outs, and subsequent failure of the procedure.

Step 5: Bolster preparation and suturing

Two-inch Surgicel bolsters are created by rolling cut segments and securing each end with a 3-0 Vicryl tie. Nephropexy sutures are spaced approximately 1½ inches apart, so a total of two sutures are tied down over each bolster. Longer bolsters can be utilized, but are more cumbersome. We prefer to use 2-0 silk suture mounted on a SH needle for our nephropexy stitches due to its permanence, induced tissue response, and ease of tying. The SH needle is ideal for this procedure due to its tapered point and relatively flat curvature, allowing gentle, yet lengthy passage beneath the renal capsule. Each suture is cut into a 7-inch length, which is optimal for throwing a single intracorporeal suture.

The upper pole of the kidney is secured to the cut edge of the infrahepatic peritoneal edge by placing two sutures, first through the peritoneum and then through the adjacent region of renal capsule. This step is the reason why it is important to cut the peritoneum low enough to leave an adequate shelf beneath which the upper pole can be inserted and sutured. Care should be exercised to place these renal capsular sutures just where the convexity becomes the anterior surface of the upper pole, as more posterior placement will force the kidney into slight anterior rotation. While these sutures are being placed, the patient remains in the deep Trendelenburg position with full lateral rotation to help keep the kidney in its anatomic position. The assistant utilizes the Genzyme liver retractor to elevate the liver edge to expose this region for suture placement. The needle is passed initially from outside-to-inside through the infrahepatic peritoneal edge, and is pulled through to the appropriate length prior to passage through the capsule of the kidney to prevent sawing through this delicate structure (see Video 81.2). The needle is scythed just below the capsule for as long a length as the arc of the needle will allow. Care must be exercised to avoid entry into the substance of the renal parenchyma, which can result in vigorous and persistent bleeding, making visualization during the operation difficult. A second suture is then placed in identical fashion approximately 1½ inches medial to the first. Prior to tying either suture, a 2-inch Surgicel bolster is placed between the capsule of the kidney and the cut infrahepatic peritoneal edge (see Video 18.3). This not only aids in hemostasis, but stimulates tissue reaction and clotting between the two structures with eventual fibrous fixation. These sutures are then carefully tied down over the bolsters to a degree of visual tension that brings both into firm contact with the bolster, but is not enough to lacerate the capsule.

Once these sutures are placed, the operative assistant removes the Genzyme retractor and replaces it with a blunt instrument such as the irrigator–aspirator. This instrument is then utilized to provide temporary liver elevation, when necessary, but to more importantly provide lateral kidney retraction while the sutures are being planned and tied down. This is especially important when tying down the sutures on the convexity of the lower pole. The kidney is first held into position by the assistant and, beginning along the lateral border of the upper pole, the site for fascial and renal capsular suture placement is then mentally visualized and the assistant relaxes retraction of the kidney enough to allow better exposure of these surfaces. The sutures are then placed first through the quadratus fascia and then through the capsule of the kidney. A second suture is then placed approximately 1½ inches lower on the convexity of the kidney, and a Surgicel bolster is then positioned between the quadratus fascia in this area and the capsule of the kidney. The assistant then retracts the kidney into its appropriate position and the sutures are sequentially tied down over the bolster as described above (see Video 81.4). The process is then repeated until the kidney is firmly fixed to the quadratus fascia. This usually requires approximately four or five laterally-based sutures in addition to the two that were placed through the infrahepatic peritoneal edge (Figure 81.17).

Fornara *et al.* described a similar technique but placed only a single nonabsorbable polyester suture through the upper pole and a second through the convexity of the kidney, fixing each to the quadratus fascia [53]. McDougall *et al.* utilized a braided polyester suture

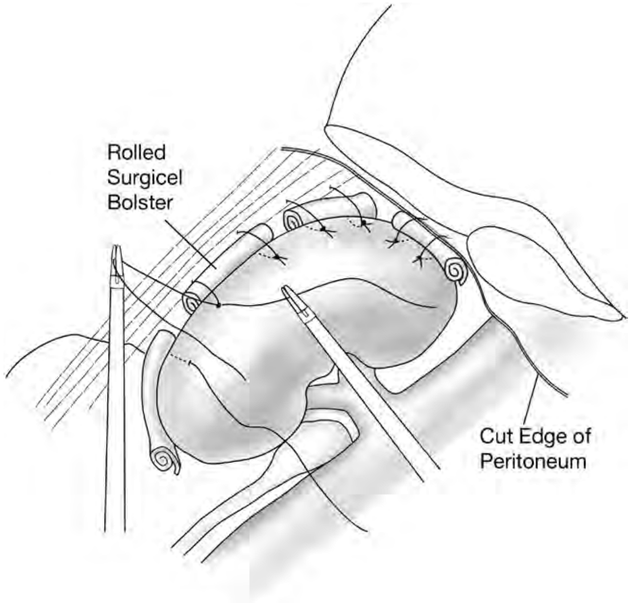

Figure 81.17 Right laparoscopic nephropexy. Two sutures are placed at a time through the quadratus fascia and renal capsule, and are tied over rolled Surgicel bolsters.

with a preformed loop on the end [58]. The suture-mounted needle is passed initially through the capsule of the kidney, then through the quadratus fascia, and the needle is brought through the loop to allow cinching into place. Once all of the securing sutures have been placed utilizing this technique, they are then tightened and secured using a Lapra-Ty suture clip (Ethicon Endo-Surgery). The cephalad-to-caudal approach for suture placement and securing of the kidney allows fixation to occur first in the areas of least tension and proceeds toward the area of maximum tension in the lower pole.

Instead of tacking sutures, Plas *et al*. utilized a polypropylene mesh shaped like an ellipse to cover the kidney in its sagittal extension and then secured the mesh to the abdominal wall with staples [59]. Previously, an absorbable Polyglactin mesh had been utilized for their initial six patients; however, this was ultimately abandoned after a patient developed symptomatic recurrent mobility 3 months following surgery [59].

Step 6: Exiting the abdomen and port closure

After tying the final suture, the operating table is returned to its neutral position and the kidney is visually monitored to ensure that it maintains its fixed position in the retroperitoneum. Final inspection of the areas of dissection for hemostasis, exiting the abdomen, and port site closure are then performed in identical fashion to that described for laparoscopic nephrectomy.

Postoperative care

The immediate postoperative care for patients having undergone nephropexy is identical to that described following laparoscopic simple nephrectomy, with the following exceptions. The patient is usually kept in a supine position overnight to prevent tension at the securing sutures and to allow clotting to begin in the region of the Surgicel bolsters. Postoperative immobilization following open nephropexy procedures has ranged from 1.5 to 10 days with resultant success rates of 36.3–94.1% [167–170]. Fornara *et al.* noted no difference in success rates following immobilization for 3 days in their initial 11 patients and their next 12 patients who were immobilized anywhere from 1 to 3 days [54]. This series and our own experience indicate that protracted immobilization following the procedure is not necessary. Ambulation is initiated the following day and once the patient has demonstrated stable mobility, the Foley catheter is removed. If bowel sounds are present, the diet can usually be advanced rapidly due to the limited mobilization of the bowel.

The patient is typically discharged home on postoperative day 1 or 2 and is instructed to refrain from all "vertical jarring" activities such as jogging, horseback riding, etc. for 4–6 weeks to allow stable fixation of the kidney. A follow-up nuclear renal scan is then performed in the sitting position and is compared to the patient's preoperative sitting images. This should demonstrate a postoperative position of the kidney in the sitting position nearly identical to the supine images and resolution of any previously demonstrated reduction in 1–2 min perfusion, relative renal function, or tracer excretion (see Figure 81.3).

Results

The long-term results of four of the larger published series of laparoscopic nephropexy (Table 81.11) reveal that symptomatic improvement or cure is noted in 92–100%, with radiographic improvement in 90–100% of those with sufficient follow-up using suturing and mesh graft fixation techniques [54, 58, 59, 170]. In Plas et al.'s series, one of 30 patients developed a symptomatic recurrence when she felt a "tearing" sensation in her flank during vigorous exercise 3 months following her surgery, and once again developed symptomatic nephroptosis [59]. This was one of the patients who had an absorbable mesh graft fixation performed. A comparison of 23 laparoscopic to 12 prior open nephropexy procedures performed at a single institution demonstrated only slightly longer mean operative time of 61 min versus 49 min, but reductions of postoperative pain medication (15 mg vs 38 mg morphine equivalent), mean hospital stay (3.7 days vs 16 days), and complications (13% vs 33%) for the laparoscopic relative to the open approach [54].

Complications

As with the other renal laparoscopic procedures, any of the intraoperative or postoperative complications related to access entry, dissection, or port closure as described for simple nephrectomy are possible with laparoscopic nephropexy, with the exception of Endo-GIA stapler misadventure. Summarizing the laparoscopic series outlined in Table 81.11, complications include bleeding requiring blood transfusion (2.5%), minor retroperitoneal hematoma (1.7%), urinary tract infection (0.8%), nausea/vomiting (0.8%), and symptomatic recurrence (0.8%) [54, 58, 59, 170]. Other complications reported for open nephropexy, though not occurring in these series, remain theoretic possibilities and include genitofemoral entrapment or neuralgia, costal osteomyelitis, hydronephrosis, and obstruction or stenosis of the UPJ [54, 55, 171]. Another potential risk when utilizing a permanent mesh would be the risk of

Table 81.11 Results of laparoscopic nephropexy.

Series	Technique	TP/ RP	Operative time (mean, min)	Analgesia (morphine equiv, mg)	LOS (mean, days)	Radiographic success	Symptomatic success	Follow-up	Complications
Plas *et al.* [59]	Mesh graft	30/0	154	16	6	9/10 (90%)	11/13 (85%) cured	5.9 years (median)	1 symptomatic recurrence
McDougall *et al.* [58]	Suturing	12/2	246	37	2.6	13/14 (92.8%)	21% cured 71% improved	3.3 years (mean)	1 vomiting and dehydration
Fornara *et al.* [54]	Suturing (two sutures)	23/0	49	15 and 550 mg ibuprofen	3.7	23/23 (100%)	91% improved 2 not accessed	13 months (mean)	3 (13%) 1 UTI 2 retroperitoneal hematoma
Gozen *et al.* [170]	Suturing (two sutures)	0/51	95	4 patients only- 35 mg; all diclofenac	8 (median)	48/51 (94.1%)	95% cured 7 not accessed	98 months (mean)	3 blood transfusion

TP, transperitoneal; RP, retroperitoneal, LOS, length of stay; UTI, urinary tract infection.

Table 81.12 Key points.

- Equal efficacy with improved postoperative analgesia requirements, hospital stay, and convalescence have been demonstrated for most laparoscopic renal procedures for benign disease relative to their open counterparts
- A transperitoneal or retroperitoneal approach can be utilized for most laparoscopic renal procedures and is largely dependent upon surgeon preference and training
- The Harmonic scalpel is an extremely helpful adjunct instrument for performing laparoscopic renal surgery
- Laparoscopic nephrectomy is an accepted and effective option for most benign conditions requiring removal of the kidney, with the possible exceptions of xanthogranulomatous pyelonephritic and tuberculous kidneys
- Laparoscopic heminephrectomy can be performed for duplication-associated anomalies when a symptomatic, poorly functioning upper or lower pole moiety is affected
- Preoperative cystoscopic placement of a ureteral catheter for intraoperative methylene blue collecting system injection is helpful when performing laparoscopic heminephrectomy, peripelvic cyst ablation, or calycealectomy
- Laparoscopic decortication of simple, peripelvic, and ADPKD-associated renal cysts is an excellent first-line treatment option with durable symptomatic improvement
- Laparoscopic peripelvic cyst decortication is associated with a higher rate of collecting system injury and there is no consensus regarding the safety of laparoscopic decortication of Bosniak II and III category cysts
- Laparoscopic calycealectomy is best suited for anterior-based, stone-bearing calyceal diverticula
- Laparoscopic nephropexy has >90% radiographic and 85% symptomatic success rates on mean follow-up of >3 years in several series

infection or rejection of the mesh, which was reported to be 1% in a review of 500 cases during which it was used for hernia repair [59, 172].

Conclusions and key points

Nearly 20 years after Clayman *et al*. ushered in the new era of laparoscopic surgery in urology with their report of the first case of laparoscopic nephrectomy [173]. The procedure is now commonplace at many university and community hospitals. Increased experience with this operation has resulted in a more refined understanding of the anatomy and ergonomics of laparoscopic renal surgery, leading to further application to other forms of benign disease. Partial extirpative and reconstructive renal procedures, such as heminephrectomy, renal cyst ablation, calycealectomy, and nephropexy, are now being performed laparoscopically with regularity, and have led to improvements in postoperative morbidity and convalescence similar to laparoscopic nephrectomy. In the process, urologists have had to familiarize themselves with physiologic responses, anatomic exposures, and complications that are unique to the laparoscopic approach. The key points are summarized in Table 81.12.

The expansion of patient educational materials available via the Internet, health maintenance organizations seeking shorter hospital stays, and the desire for employers to minimize periods of convalescence have further fueled the growth of laparoscopic renal surgery. Technologic advances in instrumentation, robotics, tissue welding, hemostatic agents, and ablative devices have already begun to impact how we are currently performing these operations. These advances combined with the limitless vision of the urologist's mind will ultimately determine how the term "minimally invasive renal surgery" is defined in the next 20 years.

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CHAPTER 82

Laparoscopic Living Donor Nephrectomy

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Introduction

Following the description of living laparoscopic donor nephrectomy (LLDN) in 1995, the procurement of kidneys has changed dramatically [1]. This change in technique has paved the way for increased living kidney donation. In fact, the United Network of Organ Sharing (UNOS) reported that the number of living donations performed in the USA exceeded the number of deceased donations for the first time during the year 2000. The addition of hand-assisted techniques has also arguably increased the transition from open to laparoscopic procurement in many centers. During the initial decade following the first LLDN, from 1995 to 2004, the number of living kidney donations increased from 3395 to 6647 according to the Organ Procurement and Transplantation Network (OPTN) Scientific Registry of Transplant Recipients (SRTR) annual report. Since that time, the number of living kidney donors decreased over the next 4 years to approximately 6000. Resurgence in the number of living donors was seen in 2009 and reported to be 6388 at this time (Figure 82.1). The laparoscopic approach has decreased some disincentives to donate and, depending on hospital volume and surgeon experience, there are few remaining indications for open donor nephrectomy.

Preoperative evaluation

Any potential living kidney donor must undergo extensive medical evaluation to rule out medical comorbidities and to try to lessen the chance that the donor is in need of renal replacement therapy in the future. This medical evaluation typically centers on a transplant nephrologist. It is also routine for potential donors to undergo a psychologic evaluation to deem whether they are fit mentally for donation and to assess for any coercion involved. It is important for any patient for whom donation is not straightforward because of medical reasons, surgical anatomy, or social reasons, to be presented in a multidisciplinary conference, which may consist of the donor coordinator, nephrologists, donor and transplant surgeons, and genitourinary radiologist.

The evaluation by the donor surgical team is an important part of the process as it allows for selection of the surgical technique to be employed, identification of the appropriate kidney for donation, and proper consultation regarding the risks of kidney donor surgery. The surgical evaluation provides an additional opportunity to identify issues that may have not been revealed during prior visits, as well as to focus on the details specific to donor surgery. The recipient identity, their relationship to the donor, and the cause of their renal failure is reviewed. Particular attention is focused on whether the patient has any urologic history, such as gross hematuria, nephrolithiasis, pyelonephritis, renal cysts or tumors. At times, new issues may come up at this visit, or perhaps the social situation of the donor has changed in a way that may affect their candidacy or willingness to be a donor.

The physical examination includes measurement of vital signs and allows for confirmatory measurements

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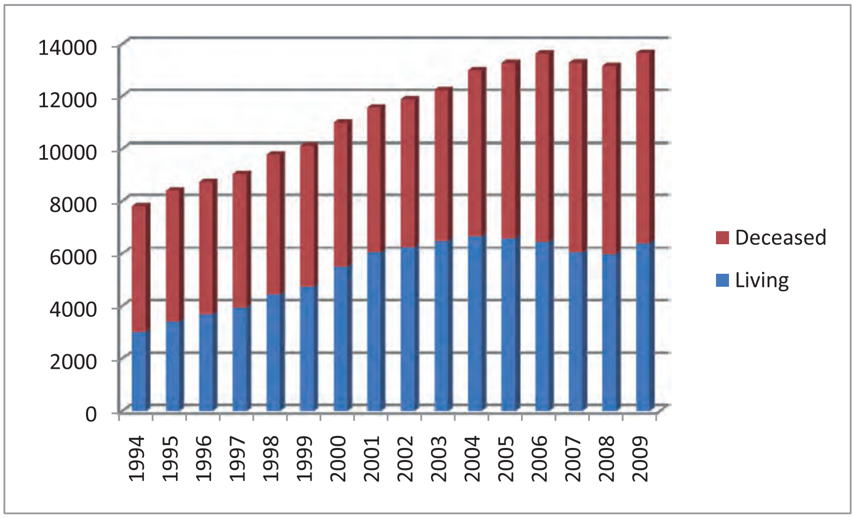

Figure 82.1 Number of living versus deceased kidney donors from 1994 to 2009.

of height and weight for the computation of the patient's body mass index (BMI). Particular attention is paid to the abdominal exam to evaluate the patient's body habitus and to document any prior surgical scars relevant to the surgical approach. This simple evaluation is essential to identify patients appropriate for minimally invasive donor surgery.

Donor anatomy is evaluated with multidetector computed tomographic (MDCT) angiography/urography with reconstructions. Multiphase MDCT images demonstrate the size of each kidney and the amount of renal parenchyma. Rapid symmetric uptake of intravenous contrast, combined with prompt excretion and drainage, documents the relative renal function and can obviate the need for routine renal scans. Donors found to have disparities in renal size, contrast uptake or excretion, or renal scarring are further studied with a MAG3 renal scan to ensure adequate renal function. The affected kidney is then chosen to ensure the donor is left with the highest functioning renal unit. Delayed urogram phases also document the anatomy of the collecting system of each kidney and ureter. Anomalies such as a partial or complete ureteral duplication could be missed without the urogram phase. Although uncommonly found, such anomalies could potentially alter the surgical approach. Incidental intra-abdominal pathology is often discovered at the time of MDCT imaging. Adrenal nodules are detected in a small proportion of patients and present a clinical challenge. If the adrenal lesions meet CT criteria for benign adenoma, and a functional metabolic work-up is negative, proceeding with donation is reasonable.

In one study, approximately 30% of kidneys evaluated using MDCT technology were found to have incidental renal pathology, such as low density lesions too small to characterize, renal cysts, and calyceal calcifications [2]. This relevant surgical information does not necessarily preclude donation. Reviewing over 850 laparoscopic and open donor nephrectomies from 2000 to 2007 at UCLA, approximately 19% of patients were found to have incidental renal findings, such as low density lesions considered "too small to characterize" on preoperative evaluation (unpublished data). Alternatively, large or complex renal cysts require attention and may necessitate removal of the affected kidney.

An increasing number of calyceal calcifications are identified with high-resolution CT-based imaging and there is no clear recommendation on how to treat these potential donors. Patients with a history of nephrolithiasis or those found to have bilateral, multiple unilateral, or large renal stones are generally not considered candidates for donor nephrectomy. In our experience, donor candidates found to have a single small asymptomatic calcification, particularly if they are older donors, undergo a thorough metabolic work-up. If no abnormalities are detected, it may be reasonable to proceed with donation with appropriate counseling, removing the affected kidney.

CT-based imaging can also supplement the patient selection process by elucidating the amount of retroperitoneal fat. The amount of perirenal fat and the distance the kidney lies from the psoas muscle are tools that can be used to select higher BMI donors who will still be amenable to a laparoscopic approach (Figure 82.2). The majority of transplant centers included in a recent survey were noted to have a donor BMI cut-off of 35, although surprisingly, 31% of those participating did not have a donor exclusion BMI [3]. This becomes particularly important in patients with complex vascular anatomy as the amount of perirenal fat can indicate a more challenging dissection, especially at the renal hilum. Vascular anatomy has become increasingly

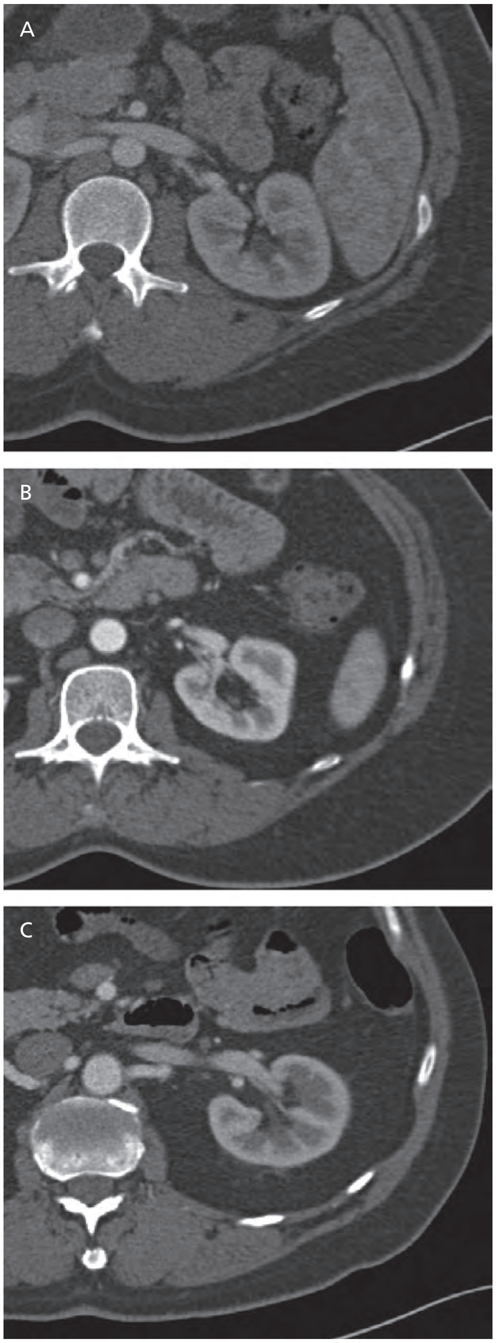

Figure 82.2 (A–C) Examples of differing amounts of perirenal fat in three patients, all with a body mass index of 33.

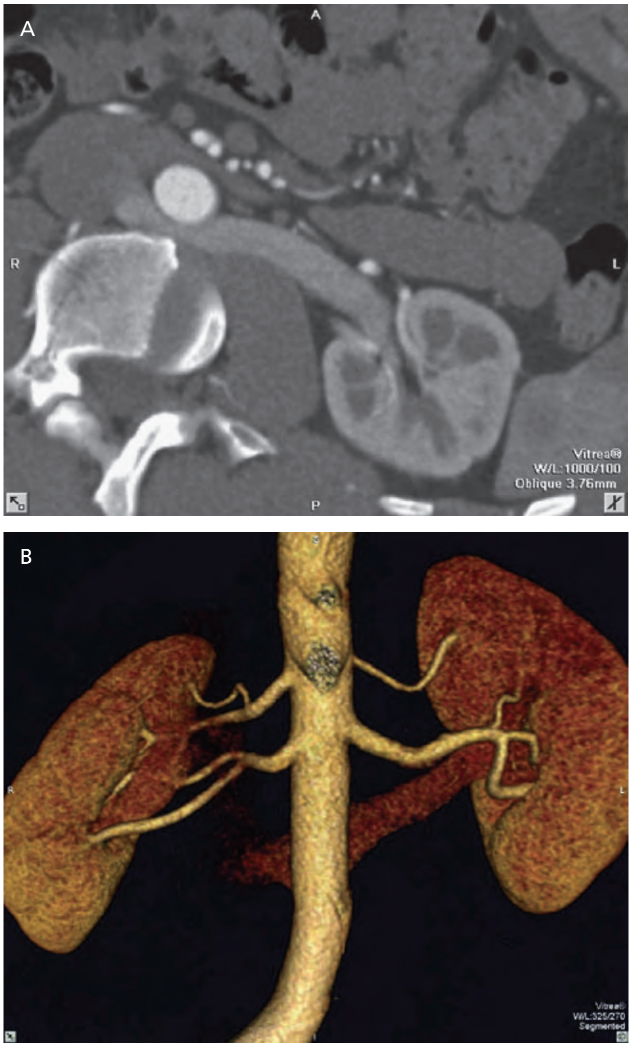

Figure 82.3 (A) MDCT showing a retroaortic vein. (B) 3D reconstruction of the same patient with a retroaortic vein and bilateral accessory upper pole arteries.

relevant to the surgical evaluation with the increasing adoption of laparoscopic approaches to kidney donor surgery, and MDCT has demonstrated impressive sensitivity to identify small vascular structures [4, 5]. The increased resolution along with three-dimensional (3D) reconstructions (Figure 82.3) may in fact increase operative safety, as well as identify small capsular and polar arteries such that attempts can be made to preserve these structures if indicated (Figure 82.4). If there are two symmetric kidneys, the left kidney is traditionally preferred due to the longer renal vein length. A right nephrectomy may be preferred when the left kidney is found to have more than two arteries. However, depending on the institution, arterial anatomy that is complex should be reviewed on a case-dependent basis with the donor and transplant surgeons. Rarely has venous anatomy alone precluded a left-sided LLDN in our series.

Surgical risks

It is imperative to highlight possible complications to healthy donors when obtaining the informed consent. The possibility of open conversion, although low, is emphasized with every potential donor. The donor needs to understand the intraoperative risks, such as

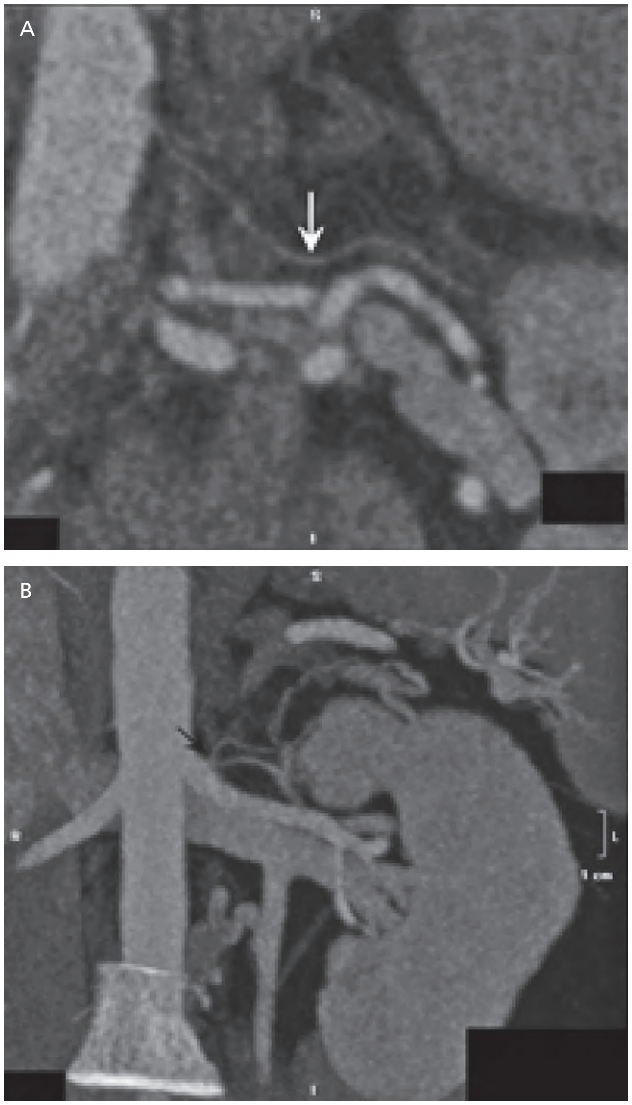

Figure 82.4 (A) 1-mm left upper pole accessory renal artery (arrow). (B) Single left renal artery with early bifurcation (arrow) of two small capsular arteries. (Reprinted with permission from the American Journal of Roentgenology.)

bleeding that could result in a transfusion; injury to organs such as bowel, colon, pancreas, adrenal gland, diaphragm, stomach, spleen, liver, such that repair or additional operations are needed; and other major complications such as deep vein thrombosis, myocardial infarction, stroke, and death. Additional complications, such as neuropathy, chylous ascites, hernia formation, pain, and wound complications, need to be discussed as well, so the donor has a realistic expectation of the postoperative course.

This direct discussion can reveal patients who are not or no longer willing to proceed. A medical alibi should be offered, to ensure that the patient does not feel undue pressure to proceed with the process that may have taken some time to complete. This offers an escape from donation while still maintaining the patient's status in the recipient's opinion.

Surgical technique

Regardless of the different approaches, the steps of the living donor nephrectomy should be similar. Although different techniques and approaches have been described, the transperitoneal approach is most often utilized [3]. After induction of general anesthesia and placement of a Foley catheter and orogastric tube, the patient is placed in a modified or near-flank position. Some flexion of the table is used without the kidney rest. The extremities and all pressure points are meticulously protected with pillows, and the patient is secured to the table with tape. For purely laparoscopic donation, the pubic area is also prepped into the field.

In case of a transperitoneal access, the pneumoperitoneum is obtained through a Veress needle puncture, an optical trocar access, or a Hasson technique. There is no clear advantage between access techniques and the access approach is largely surgeon dependent; however, the open approach (Hasson) has been reported to have fewer complications in select series [6–8]. The position of the trocars is operator dependent. A classical triangular diamond-shaped configuration with the camera port in the middle is the traditional teaching. Our technique utilizes a linear port configuration along the pararectal line, with the camera placed at the most cephalic position in order to obtain a better ergonomic position for the surgeon and camera holder (Figure 82.5).

After obtaining access, the procedure starts with mobilization of the colon. The colon is displaced medially by dissection along the line of Toldt and careful reflection of the colonic mesentery is performed. Care should be taken to not continue the dissection lateral to the kidney at this point. Most of this dissection can be done with a combination of sharp and blunt dissection with a scissor/ultrasonic shears and kittner/grasper. For a left-sided donor, the colon, pancreas, and spleen are mobilized to the level of the diaphragm. The liver is mobilized in an analogous manner for right-side donor surgeries as well as kocherizing the duodenum. The lateral attachments of the kidney are left in place to prevent the kidney from falling medially. Once the colon is completely mobilized, the upper pole of the kidney is dissected. In order to facilitate this part of the procedure, aggressive mobilization of the spleen is recommended as mentioned above (see Video 82.1). This is obtained by incising the posterior peritoneum to the level of the crus of the diaphragm. With complete reflection of the spleen and tail of the pancreas, the adrenal gland and renal vein are identified. It is helpful for the upper pole dissection to introduce a fourth trocar off the tip of the 11th or 12th rib to aid with lateral and downward retraction of the

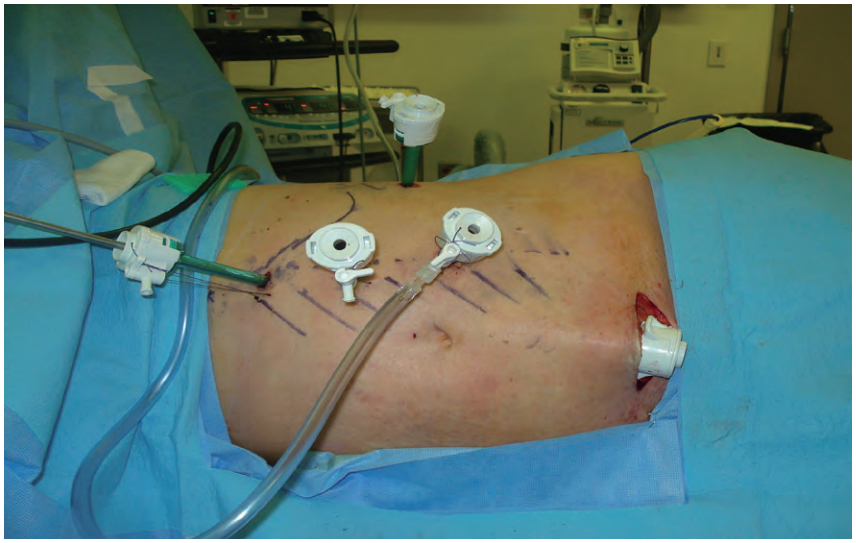

Figure 82.5 Patient positioned in operating room with four 5-mm ports with the camera most cephalad (left). A low transverse extraction site is shown with a 15-mm port in place.

kidney. Care is taken to do as little retraction as possible directly on the kidney, as the fat superior and/or lateral to the kidney can often be retracted without touching the organ. With inferior/lateral retraction on the kidney, the plane between the adrenal gland and the upper pole of the kidney is meticulously dissected to the renal hilum (see Video 82.2). During the adrenal dissection, care has to be taken to avoid small upper pole accessory arteries or capsular branches that may not have been previously detected by preoperative imaging.

Once the upper pole of the kidney has been isolated, attention is moved inferiorly to the identification of the gonadal vein and ureter. An alternative approach would be to start with the gonadal/ureter dissection before the upper pole. Although early data recommend transection of the gonadal vein *en bloc* with the ureter at the level of the iliac vessels [9–11], more recent studies have shown that the gonadal vein can be ligated safely 2–3 cm from the renal vein with dissection between the ureter and the gonadal vein itself (see Video 82.3) [12]. The advantages of this technique are believed to be improved elevation of the kidney and easier access to the lumbar vein. Whether the gonadal vein has been divided or not, the ureter is still elevated and dissected distally to the level of the iliac vessels. Care is taken to not strip the ureter, and division of attachments is recommended to be performed with bipolar energy, such as the ultrasonic shears. After completing the ureteral dissection, the ureter is then elevated along with the lower pole of the kidney with a blunt-tipped instrument all the way to the sidewall and dissection of the posterior attachments is bluntly performed. This helps with further elevation and exposure of the renal hilum. The dissection towards the renal hilum is typically medial to the gonadal vein stump and continued upwards to the level of the lumbar vein. If a lumbar vein is identified, it is clipped and transected. Alternatively, the lumbar vein can be stapled simultaneously with the renal artery. Meticulous dissection is than performed around the renal hilum and the renal artery is isolated and dissected to the level of the aorta. Depending on the donor anatomy, the adrenal vein is often divided if thought to significantly aid in length of the renal vein. If the lumbar or adrenal vein is clipped, care must be taken to avoid these clips when later stapling the renal vessels.

If a pure laparoscopic dissection, at this point the extraction site incision is made. This is typically a low-transverse (Pfannenstiel-like) incision approximately at the pubic hairline. If using a hand-assisted technique, this is often a midline or transverse incision near the umbilicus. Although some authors reported shorter warm ischemia time with the hand-assisted technique, others reported that short warm ischemia time can also be obtained with the pure laparoscopic technique as well, with better cosmetic results [13]. In case of a pure laparoscopic technique, after the Pfannenstiel incision has been obtained, the fascia is identified and a subcutaneous flap is created. A vertical midline incision is made in the fascia towards the umbilicus. A 15-mm trocar is inserted as close as possible to the umbilicus. Through this port the endovascular stapler may be used as well as placement of the 15-mm EndoCatch bag for organ extraction. For right-sided cases, our preference is to staple through the inferior pararectal trocar as this angle appears to be more aligned with the inferior vena cava (IVC). Once the extraction site is created, the lateral attachments of the kidney are divided. The kidney is fully elevated with a "snake" liver retractor at the upper pole and a blunt instrument under the lower pole; this straightens the renal hilum to ensure adequate length of the vessels (see Video 82.4). The renal artery and vein are taken separately, as well as the ureter at the level of the iliac vessels with the endoscopic stapler (see Video 82.4). The organ is than placed into an endoscopic bag and extracted (see Video 82.5). Although some surgeons still prefer to ligate the artery and vein with Hem-o-lok clips, it has to be stressed that their use has been forbidden both by the Food and Drug Administration (www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfRes/res.cfm?ID=45876) and the manufacturer (www.teleflexmedical.com), since cases of dislodgement and subsequent death have been reported. Once removed, the kidney is immediately placed in ice slush and the artery flushed with cold irrigant of choice (e.g. Wisconsin's solution, lactated Ringer's with 5000 U of heparin, etc).

The fascia is closed in a running or interrupted fashion with figure-of-eight sutures per surgeon preference. If the patient is very thin, the knots are often buried. The abdomen is reinsufflated and full inspection, including of the staple lines, takes place. If there is clot or any concern for bleeding at this point, the pneumoperitoneum is decreased back to 5 mmHg and the abdomen further inspected. Our preference at this point is to place Surgicel along the adrenal dissection and area of renal hilar dissection. The ports are removed under direct vision and an attempt at suctioning out the insufflated abdomen is performed. Skin sites are then closed in a subcuticular fashion.

Postoperative care

The orogastric tube is removed prior to extubation. The postoperative management should include serial hematocrits for the first 24 h and as needed. We routinely check a hematocrit in recovery and in the morning. The Foley catheter should be removed early in the morning of postoperative day 1 unless there is a concern regarding urine output. It is advised that the patient starts ambulating as soon as possible, whether this is in the evening of surgery or first thing in the morning at the latest. Clear liquids may be given on the day of surgery and diet advanced on postoperative day 1. If ketorolac is used, there is often little need for additional narcotics in these patients. Consideration should be given to using acetaminophen to try and reduce narcotics to lessen postoperative ileus. It has been shown that the use of intravenous ketorolac 30 mg every 8 h for the first 24 h may reduce hospital stay without increasing the risk of bleeding or renal dysfunction [14]. If the patient responds well to the pain and there are no contraindications, the patient could be discharged from hospital on the first postoperative day. The patient is typically seen by the surgeon 7–14 days later for a regular check up. Normally, if the postoperative course has been regular, there is no need for laboratory tests at this time. It is recommended that the patient should be seen by their primary care physician and have a creatinine drawn and blood pressure checked within 3 months of surgery as a baseline. It is important to advise donors about avoiding nephrotoxic medications if possible, including nonsteroidal anti-inflammatory drugs (NSAIDs) on a chronic basis, since this may result in loss of kidney function. There are normally no other limitations for donors who can conduct a normal lifestyle without restrictions.

Outcomes and discussion

LLDN is now a universally accepted alternative to open donor nephrectomy. A recent meta-analysis as well as an OPTN database analysis concluded that both approaches for procurement have equal effectiveness [15, 16]. Moreover, potential benefits to the laparoscopic donor include decreased pain, shorter hospital stay, improved cosmesis, and faster convalescence, as has been shown with various laparoscopic surgeries.

Complications of LLDNs have been reported to range from 5% to 29%, and the open conversion rate is generally less than 2% in larger series [11, 17–24]. Major intraoperative complications, renovascular complications, and need for open conversion have been acceptably low in most large centers. This coupled with the noted postoperative advantages has justified the transition to laparoscopic procurement. In turn, the minimally invasive technique is thought to be a contributing factor of increased living donation since it became available.

Open conversions are rare but are often the result of renovascular complications. In a reported series of 600 LLDNs, there were eight renovascular incidents (1.3%), all but one of which required open conversion [20]. Similarly, 10 of 12 conversions in another donor series were due to vascular injuries [19]. One cause of this complication is secondary to stapler malfunctions. Although there was a stapler misfire in our series on an accessory artery (0.13%), we prefer this method for transecting the renal vessels [24]. In addition, the use of nonabsorbable polymer ligating clips (Hem-o-lok) on the renal artery in living donors is contraindicated [25]. Vascular injuries with the Veress needle during access are very uncommon as well; estimated to occur in around 0.1% [6]. Veress needle access is utilized in 75% of centers that employed the pure laparoscopic approach according to a survey [3]. In our experience, if difficulty is encountered upon insertion of the Veress needle, or in select obese patients or those with multiple prior incisions, direct entry with a visual trocar in a desufflated abdomen is attempted. An alternative method would be an open or Hasson technique.

Two separate studies have evaluated the use of intraoperative systemic heparin given to the donor prior to renal artery ligation during LLDN [26, 27]. Although neither study was randomized, both concluded that this was not necessary and did not increase the risk of thrombosis in the graft. Further, it may increase the risk of intraoperative or early postoperative bleeding, and the use of protamine for reversal has the risk of stroke, pulmonary hypertension, and anaphylaxis. Even so, the use of heparin and protamine is still practiced in most centers according to a 2008 survey [3].

There has also been controversy as to when to perform right-sided LLDN and whether it should be done. Much of this stemmed from the concern for a shorter right renal vein and very early reports of increased recipient graft thrombosis [28]. In this series, three of eight right-sided LLDN patients experienced this complication and two of the three had a duplicated renal vein; since at this time MDCT has replaced angiography to better define venous anatomy. With better preoperative imaging and surgical modifications, there were no vascular complications in the next nine patients. An increased need for back-table reconstruction due to shorter right venous anatomy has also been reported [29]. An Endo-TA stapler may be used to increase renal vein length [30] as opposed to an Endo-GIA stapler, although a modified Endo-GIA has been described for this purpose [31]. With a known shorter right renal vein, equal outcomes between right- and left-sided procedures are reported, including a recent study that concluded that right LLDN is not only faster but safer [32].

Striving to minimize surgical complications and improve outcomes is intuitive and never truer than in the circumstances surrounding healthy organ donors. The use of ketorolac may be controversial in this population but it has been shown that its use in surgical patients as well as in donors decreases pain and narcotic requirement, and arguably speeds up the return of bowel function [14, 33]. This was previously reported to not have a significant impact on long-term renal function [33]. With less narcotic requirement and quicker return of bowel function, there is often a shorter hospital stay. In our experience, the use of ketorolac combined with minimally invasive donation has likely contributed to a median hospital stay of 1 day, with patients ambulating, passing flatus, and tolerating at least a liquid diet prior to discharge [24].

As the number of living donors has increased, along with the acceptance of less stringent inclusion criteria, there has been a renewed focus on donor safety, including long-term outcomes. Prior evidence is such that living kidney donors experience a similar survival as nondonors and do not have an increased risk of end-stage renal disease. Factors that have been associated with lower glomerular filtration rate after donation are age and being overweight, which are the same as in the nondonor population [34]. It has been estimated that after nephrectomy, donors may experience an elevation in blood pressure of approximately 5 mmHg 5–10 years postoperatively [35]. Even though the prevalence of hypertension is still lower than in the general population, without a comparative healthy control group it is unknown whether this is an increased risk. Further, in donors who do develop hypertension, it is unknown whether this would have occurred had they not donated. There has also been discussion regarding the psychologic status of donors postoperatively. Although mental health has been reported to decrease during the first year after surgery in some, the overall quality of life is reportedly higher than in the general population [35]. Establishing a donor registry would help follow these patients and better determine the true risks to potential donors, not only at the time of surgery but in the long term as well [24]. It should be emphasized that donors require lifetime follow-up to assess blood pressure, creatinine, and perhaps proteinuria, so abnormalities can be diagnosed early to prevent further complications.

Conclusions

Fifteen years have passed since the first LLDN and this technique is firmly ingrained in most major transplant centers. Because of the proven safety, equivalent outcomes, and stated benefits, it is considered the standard of care at many institutions.

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CHAPTER 83

Renal Surgery for Malignant Disease: Radical Nephrectomy and Nephroureterectomy

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Introduction

Laparoscopic radical nephrectomy (LRN) was introduced in 1991 by Clayman *et al.* [1]. This was a pure laparoscopic transperitoneal approach. Since its inception, modifications have been made to the LRN, including hand-assisted as well as the retroperitoneal approach [2, 3]. Although laparoscopic techniques have evolved, allowing urologic surgeons to perform minimally invasive partial nephrectomies for smaller renal masses, the LRN remains the gold standard for clinically localized, T2 renal masses. Additionally, some evidence suggests an advantage to radical nephrectomy in the presence of metastatic disease for cytoreductive purposes [4]. Furthermore, laparoscopic techniques have extended into the realm of treating upper tract urothelial carcinoma requiring nephroureterectomy. Now in the era of robot-assisted laparoscopic surgery, urologic surgeons are incorporating this technique for nephrectomy and nephroureterectomy. This chapter will review the indications, techniques, and results for laparoscopic and robotic radical nephrectomy and nephroureterectomy.

Indications/contraindications for nephrectomy

Indications for the use of LRN or robot-assisted laparoscopic radical nephrectomy (RLRN) include clinically localized T2 or T3 disease. Whenever possible, T1a renal masses are removed through the use of a partial nephrectomy [5]. The increased risk of cardiovascular mortality associated with decreased glomerular filtration rate (GFR) has been well documented [6]. This reduction in GFR has also been demonstrated in those who undergo radical nephrectomy for T1b lesions when compared to those who undergo partial nephrectomy [7]. Decreasing the risks associated with a compromised GFR, coupled with the sound oncologic data for nephron-sparing surgery, has led to the recommendation for partial nephrectomy for complex or T1b renal masses [8, 9]. If not amenable to minimally invasive techniques, then an open partial nephrectomy should be considered. Finally, LRN or RLRN may also be used in the setting of a cytoreductive nephrectomy in order to reduce the overall tumor burden when the metastatic disease burden is smaller in size than tumor burden within the kidney [4].

General contraindications are the same as for open radical nephrectomy. These include significant coagulopathy or comorbidities that preclude the patient from undergoing general anesthesia. Reports have been published regarding the minimally invasive management of a renal vein thrombus, but this is limited to highly experienced centers [10]. Previous abdominal surgery has not demonstrated an increased risk of either complications or need for conversion. Although previous surgery at the same site has demonstrated increased operative time and hospital stay, it is not a contraindication to performing laparoscopy [11].

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Preoperative evaluation and patient preparation

The preoperative work-up for a patient with a renal mass is no different for a LRN from that for an open radical nephrectomy. This includes a detailed history and physical examination, a complete blood count, serum electrolytes, coagulation panel, calcium, and alkaline phosphatase. A chest X-ray or chest computed tomography (CT) scan is required to screen for pulmonary metastases. A bone scan is unnecessary in the absence of bone pain or an elevated alkaline phosphatase. If the serum creatinine is elevated, a 24-h urine creatinine level and possibly a MAG-3 or DMSA renal scan may be needed to assess contralateral renal function. Usually the patient presents with abdominal imaging demonstrating a renal mass. If abdominal imaging is inadequate, a three-phase CT or magnetic resonance imaging (MRI) is required to document enhancement of the renal mass. Abdominal imaging may aid in hilar dissection by preoperatively identifying multiple renal arteries or adherent anatomy. If there is concern for a renal vein or caval thrombus, a MR venogram should be obtained. Finally, although lymphadenectomy for renal cell carcinoma remains controversial, careful attention should be paid on imaging to regional and retroperitoneal lymphadenopathy. Despite the European Organization for Research and Treatment of Cancer (EORTC) trial demonstrating no improvement in survival in those who underwent lymphadenectomy for localized renal cell carcinoma [12], others have demonstrated improved staging capability [13] and, in certain situations, improved survival with lymph node dissection for clinically detected lymphadenopathy [14].

The patient is kept nil by mouth after midnight the evening before surgery. The use of a mechanical bowel preparation is optional. Some prefer to use a bowel preparation in order to decompress the colon and small bowel for improved visualization and working space within the abdomen. A single dose of an antibiotic agent is given 30 min prior to the first incision to cover skin flora. Sequential compression devices are placed on the calves of the patient and initiated prior to the induction of general anesthesia, along with an optional dose of subcutaneous heparin.

Laparoscopic transperitoneal nephrectomy

Patient positioning

The patient is initially placed in the supine position upon arrival in the operating room. After induction of general endotracheal anesthesia, an orogastric tube and bladder catheter are placed. The location of the extraction site, usually an infraumbilical Pfannenstiel incision, is marked on the patient's skin to ensure a straight incision after the patient is positioned. The patient is then carefully placed in a modified lateral decubitus position, angled at approximately 30º from the ground. The patient's flank overlays the kidney rest, an axillary role is placed, and an additional roll is placed longitudinally along the patient's back to support the thoracic and lumbar spine. Both legs are kept straight with a pillow or other padding placed behind the knees for support. Thick tape is used to secure the patient to the table at several points in order to prevent sliding during the procedure should the table require rotating (Figure 83.1). Finally, the abdomen is prepped sterilely, along with the corresponding flank in case of a need to convert to an open procedure.

Access

The abdomen is insufflated to a pressure of 15–20 mmHg utilizing a Veress needle. Once sufficiently insufflated, a 12-mm dilating trocar is placed with the use of a 0º lens to guide its position into the abdomen at the level of the umbilicus. The 0º lens is exchanged for a 30º 10-mm laparoscopic lens, and the abdominal contents are inspected for any injury from either the Veress needle or the first trocar. The Hasson approach to abdominal entry can be used, depending on surgeon comfort. This may be useful in the case of previous abdominal surgeries, though the utilization of Veress needle access is documented to be safe in this patient group as well [15]. A second 12-mm trocar is placed at the level of the umbilicus in the anterior clavicular line. A third, 5-mm trocar is placed approximately 8 cm cephalad to the umbilical trocar in the midline. For a right nephrectomy, an additional 5-mm port may be placed inferior to the subxiphoid process in order to assist with liver retraction. If the patient's abdomen is particularly obese, all respective port positions may need to be placed laterally in order to account for abdominal wall distortion. Furthermore, for particularly large renal masses, all 12-mm ports should be used to allow for maximum versatility in passing a greater variety of instruments through any port location. Finally, if an additional port is needed for retraction, an ideal placement is in the previously marked Pfannenstiel incision line. At the completion of the case, the extra port incision is extended and used to extract the specimen.

Procedure

Depending on the side of the procedure, the white line of Toldt is incised sharply without electrocautery, thus eliminating the risk of bowel injury due to thermal

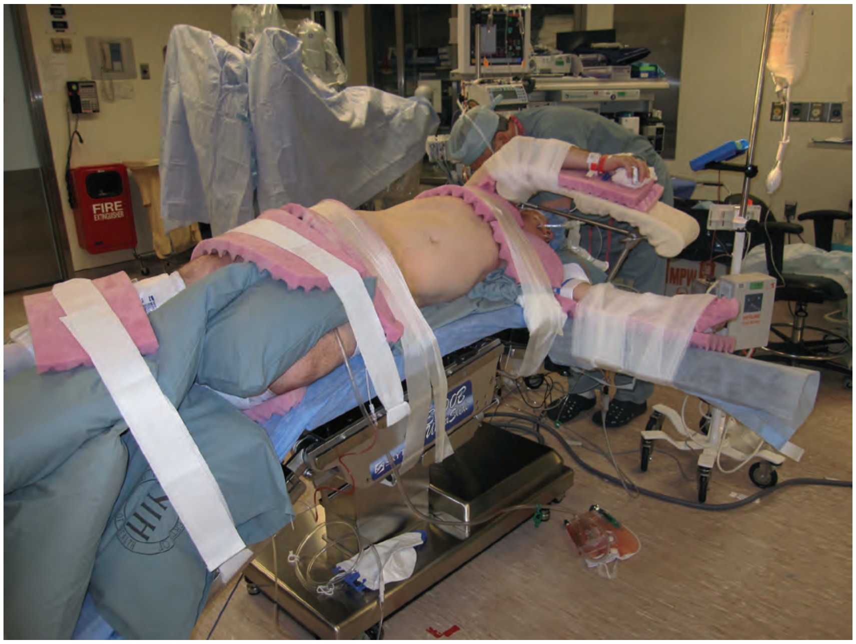

Figure 83.1 Patient position for a transperitoneal laparoscopic or robotic-assisted radical nephrectomy.

spread. A plane is developed between the posterior mesenteric and anterior perirenal fat using a combination of blunt and sharp dissection. The respective colon is mobilized medially from the iliac vessels to the respective hepatic or splenic flexure.

For a right nephrectomy, the hepatic flexure is released by dividing the renocolic ligament. This allows for further medial mobilization of the colon. The duodenum is mobilized using sharp dissection. Minimal use of blunt dissection is encouraged around the duodenum to avoid inadvertent serosal injuries. Duodenal mobilization is completed after gaining adequate exposure to the inferior vena cava (IVC) (also referred to as a Kocher maneuver).

The left colon, in the case of a left nephrectomy, is mobilized similarly with a combination of blunt and sharp dissection. The splenorenal ligament and splenophrenic attachments are divided in order to mobilize the spleen medially, *en bloc* with the splenic flexure, which provides medial reflection of the tail of the pancreas. This maneuver is important to minimize the risk of injury to the tail of the pancreas during left hilar dissection. Complete splenic mobilization often requires visualizing the stomach above the spleen. Finally, mobilization of the left colon is complete once the aorta is exposed.

Once Gerota's fascia is exposed, the psoas is identified, anterior to which is the ureter. Alternatively, the mid ureter can be found posterior and medial to the gonadal vein. This relationship is particularly important when tracing the ureter to the renal hilum in the case of a right nephrectomy. Care is taken to sweep the gonadal vein medially, separating it from the ureter and avoiding the risk for avulsing it from the vena cava. The ureter is kept intact, which allows it to be used as a handle for anterior and cephalad retraction of the kidney later in the case.

At this point the lower pole of the kidney is mobilized within Gerota's fascia. This has the potential for causing significant bleeding in the case of large, lower pole masses or if multiple parasitic vessels are encountered. To help facilitate lower pole mobilization with adequate hemostasis, electrocautery, any of a number of ultrasound-based coagulation devices, or the LigaSure (Valleylab, Boulder, CO, USA), which uses an electrical current to fuse blood vessels, may be utilized. Prior to the start of dissection, we recommend placing a small lap pad into the patient. In the event of unexpected bleeding, this can be used to improve visualization, or in the worst case, tamponade bleeding to allow time for open conversion.

With the lower pole of the kidney mobilized, the ureter can be traced cephalad to the renal hilum. Care needs to be taken when dissecting toward the renal hilum in the event of a lower pole accessory vessel. Retracting anteriorly and cephalad on the kidney allows for better exposure to the renal vein and artery. Judicious use of energy-based dissection may be required to divide the fibrous lymphatic tissue often surrounding the renal artery.

For a left nephrectomy, ensuring the left renal artery is positioned posterior to the exposed renal vein ensures that the superior mesenteric artery is not mistaken for the left renal artery. Next, when the left renal vein is isolated, the gonadal vein can be clipped and divided if necessary. Caution should be exercised at this point to prevent avulsing a potential lumbar vein that can feed into the posterior surface of the left renal vein. If the adrenal gland is to be taken, the left adrenal vein can be clipped and divided at this point. Once the renal artery and vein are isolated, an endovascular stapler or clips are used to secure the artery and vein. Once the artery has been divided, if the renal vein does not decompress as expected, thus raising the concern for a renal vein thrombus, or if there is a known renal vein thrombus preoperatively, laparoscopic ultrasound is employed to ensure the thrombus has retracted completely before dividing the vein.

After the artery, followed by the vein, has been divided, the decision is made whether to preserve the adrenal gland or to take it with the specimen. For large, central tumors or those located in the upper pole of the kidney, removing the adrenal gland with the kidney should be performed in order to ensure there are negative margins. In the case of a right nephrectomy, moving superiorly along the IVC will expose the short, right adrenal vein. Care should be taken as this is a delicate vein and avulsing it can lead to significant hemorrhage. Once divided, using energy-based dissection can facilitate expeditious mobilization of the kidney and adrenal gland from the surrounding renal fossa, while also securing potential parasitic vessels feeding the tumor. Care is taken superiorly to avoid inadvertent injury to the diaphragm. Also, at this point, the ureter is clipped and divided, completely freeing the specimen. When taking the left adrenal gland, either the left renal vein can be stapled proximal to the insertion of the adrenal vein, or the adrenal vein can be clipped and divided separately.

In the case of an adrenal-sparing nephrectomy, energy-based dissection can be used to effectively dissect and coagulate any small feeding vessels between the kidney and the adrenal gland.

Current evidence does not suggest a benefit to performing a lymph node dissection for T1 or T2 disease in the absence of clinically positive nodes [12, 16]. However, retrospective data do suggest some benefit to improved staging in those with clinically detected nodal disease [13]. Adding to the argument in favor of extended lymphadenectomy are data from Pantuck *et al.*, who demonstrated improved survival in those patients with metastatic disease who underwent cytoreductive nephrectomy and lymphadenectomy prior to immunotherapy compared to those who did not receive an extended lymphadenectomy [14]. Depending on the clinical situation and surgeon preference, the lymph node dissection can be performed either laparoscopically or robotically, and is not precluded based on a minimally invasive approach.

Finally, the specimen is entrapped in any commercially available laparoscopic organ retrieval device. The specimen, depending on the size of the tumor, can be removed through a small extension of either the lateral or umbilical trocar incisions, or through a separate, cosmetically preferable, Pfannenstiel incision. Another option for specimen extraction is through morcellation. Though not commonly performed, it provides for a smaller incision compared to the larger Pfannenstiel incision for whole-specimen extraction [17].

Laparoscopic retroperitoneal radical nephrectomy

Advantages/disadvantages

The retroperitoneal approach to an LRN can be advantageous in cases where the patient has had prior abdominal surgeries. However, if the patient is particularly obese or has a large amount of retroperitoneal adipose tissue, proper orientation can be difficult. Improper orientation and loss of appropriate landmarks can lead to significant operative challenges and even inadvertent caval transaction when mistaken for the renal vein [18]. Furthermore, previous renal surgeries or renal infections can lead to significant perirenal adhesions, thus adding additional difficulty to the retroperitoneal approach. Finally, large renal masses with multiple parasitic vessels or those that may involve other organs should not be removed retroperitoneally.

Positioning

The patient is placed in the full flank position. After the axillary roll and appropriate anterior/posterior bolsters are placed, the patient is secured with thick tape to the bed. The table is flexed to extend the space between the 12th rib and the iliac crest.

Procedure

After being prepped and draped sterilely, an incision is made off the tip of the 12th rib large enough to accommodate the surgeon's index finger. With the oblique muscles divided, the lumbodorsal fascia is incised and the retroperitoneum is entered. The surgeon's index finger is inserted into the retroperitoneum, and the psoas muscle and lower pole of the kidney are palpated (Figure 83.2). A commercially available balloon dilator that accommodates a 10-mm laparoscopic lens is inserted into the incision under direct vision. The potential retroperitoneal space is opened with the dilating balloon to a volume of approximately 800 mL (Figure 83.3). After

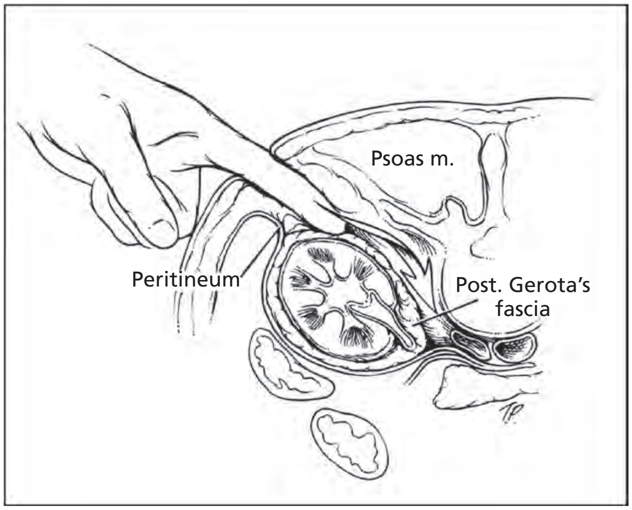

Figure 83.2 Palpation of the retroperitoneum prior to balloon dilator placement (reproduced from Pinto, P.A., Jarrett, T.W. Renal surgery in adults. In: *Retroperitoneoscopy and Extraperitoneal Laparoscopy in Pediatric and Adult Urology*. New York, Springer, 2003, with permission).

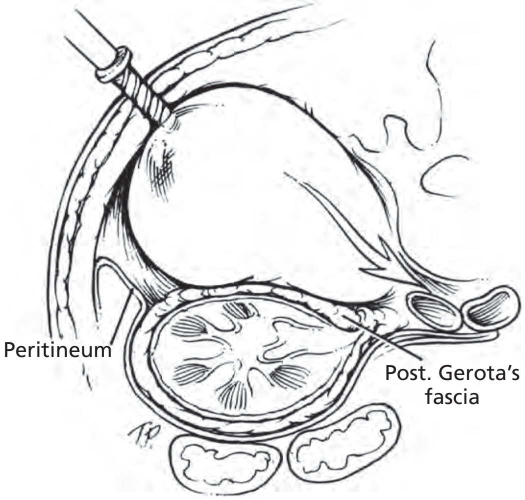

Figure 83.3 Creation of the working space with a balloon dilator in the retroperitoneum (courtesy of P. A. Pinto and T. W. Jarrett).

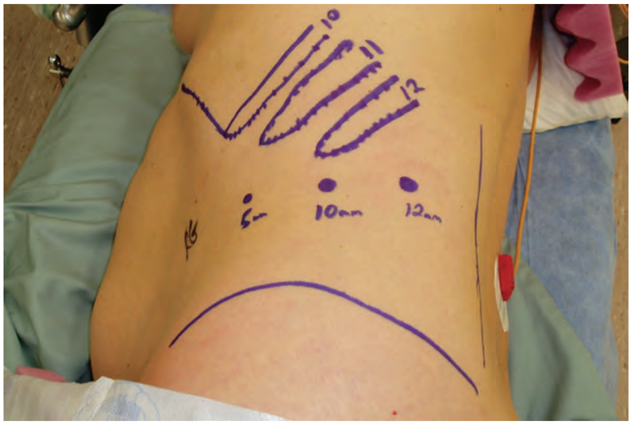

Figure 83.4 Patient position with ribs and port placements marked.

deflating and removing the balloon, a blunt-tipped trocar with a soft collar is placed into the incision. The soft collar on the inside of the incision helps maintain insufflation as well as prevent subcutaneous emphysema. Furthermore, this port does not project far into the working space, therefore not impairing the view of the kidney. The laparoscope is placed through this trocar.

Two additional trocars are placed. A 12-mm trocar is placed lateral to the camera port and approximately 2 cm cephalad to the iliac crest. A second 5-mm trocar is placed off the tip of the 11th rib (Figure 83.4). Finally, an optional additional 5-mm port can be placed off the tip of the 10th rib. When placing the ports medial to the initial camera port, the peritoneal lining must be swept medially or inadvertent peritoneal entry and bowel injury may occur.

After the 10-mm 30° lens is placed through the 12-mm inferior port, surgical orientation is achieved based upon the position of the psoas muscle and overlying ureter. At this point, the psoas muscle and tendon are dissected free of all retroperitoneal fat. Anterior and medial to the tendon will be the ureter. As with the transperitoneal approach, the ureter is traced back to the renal hilum and is used for placing traction on the kidney and hilum. Care is taken at this point as the IVC (for a right nephrectomy) or the aorta (for a left nephrectomy) is medial and in close proximity to the ureter.

For a left nephrectomy, as the ureter is traced to the renal hilum, dissection should be performed bluntly with the irrigator–aspirator in case an ascending lumbar vein is encountered entering the renal vein. If found, the vein is clipped and divided before proceeding to the renal hilum.

The ureter is traced superiorly along the medial aspect of the psoas muscle. This helps to keep the dissection in proper orientation and posterior to the kidney. The renal hilum is identified based on pulsation of the renal artery. Gerota's fascia is incised over the pulsation to expose the renal artery and vein. The artery and vein are isolated and divided as described for the transperitoneal approach.

After the kidney has been completely freed from the renal fossa and the ureter divided, the kidney is placed in a laparoscopically-deployed organ entrapment device. If the mass and kidney are small, the initial port can be extended in order to deliver the kidney. In cases where the specimen is prohibitively large, a Pfannenstiel incision is made and the space of Retzius is entered. Matin and Gill described a modified Pfannenstiel incision that is lateralized to the side of the surgery [19]. Dissection is carried down to the anterior rectus fascia and a vertical incision is created along the lateral rectus border. With the fascia and rectus muscle retracted, the transversalis fascia is divided near the pubis and the extraperitoneal space is entered. Careful blunt dissection into the retroperitoneum through the Pfannenstiel incision can allow for delivery of larger specimens through a lower abdominal incision [19].

Hand-Assisted laparoscopic nephrectomy

Advantages/disadvantages

There are several advantages to the use of hand-assisted laparoscopic nephrectomy (HALN). It is often helpful for those with little experience with laparoscopic surgery and thus can help serve as a bridge between the open and pure laparoscopic approaches. It is particularly helpful when large renal masses are encountered and there is significant risk for intraoperative bleeding. HALN also allows for the use of tactile sensation, which is useful in cases where the anatomy is obscured. Finally, it may also be used as a technique to convert from a pure laparoscopic approach. One disadvantage of this approach is that it often results in a cosmetically suboptimal incision compared to the Pfannenstiel incision when used for specimen extraction. Additionally, maintaining adequate pneumoperitoneum, and thus proper visualization, can be difficult if the hand port leaks or if the incision for the port is too long.

Position and trocar placement

Patient position is the same as for the laparoscopic approach. The details of trocar placement and nuances of various hand ports are beyond the scope of this chapter. Briefly, three major hand-port systems are commercially available. The LapDisc™ (Ethicon Endo-Surgery, Cincinnati, OH, USA) is a one-piece system that is quickly inserted into an abdominal incision the length of the surgeon's glove size. Although the LapDisc™ occupies the smallest amount of external surface area on the abdomen, each time the hand is removed, the port must be untwisted and thus the pneumoperitoneum is lost. The GelPort™ (Applied Medical, Rancho Santa Margarita, CA, USA) consists of a larger diameter system through which the surgeon can place their hand through a gel-like material into the abdomen. This outer gel sealant allows for the maintenance of the pneumoperitoneum despite the surgeon moving their hand in and out of the abdomen. The drawback of the GelPort™, however, is that it takes up a larger amount of surface area on the external abdomen and may interfere with other ports. Finally, the Omniport™ (Advanced Surgical Concepts, Wicklow, Ireland) is a cuff system that is placed through the skin incision, into the abdomen, and is inflated with a separate pump once the surgeon's hand is placed through it. The advantage of the Omniport™ is that it compensates for an excessively large incision, thus preventing leakage of the pneumoperitoneum around the port. However, each time the surgeon's hand is removed, the cuff needs to be deflated and the pneumoperitoneum is lost [20].

For a right nephrectomy, the hand port is placed in the right lower quadrant, a 12-mm trocar at the umbilicus, another 12-mm camera port in the midline approximately 8 cm cephalad to the umbilicus, and a 3- or 5-mm port immediately inferior to the subxiphoid process for a liver retractor (Figure 83.5A). For a left nephrectomy, the hand port is placed immediately below the umbilicus in the midline, followed by a 12-mm trocar 8–10 cm lateral to and at the level of the umbilicus. Finally, a third 12-mm port is placed 8 cm cephalad to the umbilicus for the camera (Figure 83.5B).

Procedure

The white line of Toldt is incised sharply while the nondominant hand through the hand port places traction on the colon medially. After the correct plane between the colonic mesentery and Gerota's fascia is entered, the colon is swept medially with the nondominant hand and the irrigator–aspirator.

For a right nephrectomy, the renocolic ligament is divided while the nondominant hand retracts the flexure medially. This exposes the duodenum and Gerota's fascia. As with the pure laparoscopic approach, the duodenum is reflected sharply. At this point, a liver retractor is placed through the subxiphoid port to elevate the liver and allow better access to the renal hilum.

For a left nephrectomy, the splenorenal and splenophrenic ligaments are divided. The hand provides gentle medial traction on the spleen to allow for exposure to the upper pole.

The psoas muscle is identified and the ureter and gonadal vessels are isolated. For a right nephrectomy, the ureter is retracted anteriorly with the hand while the gonadal vessels are swept medially with the irrigator–aspirator. On the left, the vessels are taken with the ureter. The ureter is then traced toward the renal hilum. At this point, the lower pole of the kidney is mobilized and retracted anteriorly and cephalad with the hand, while the renal vessels are dissected free with a combination of the irrigator–aspirator and energy-based dissection. In cases where a large renal mass partially

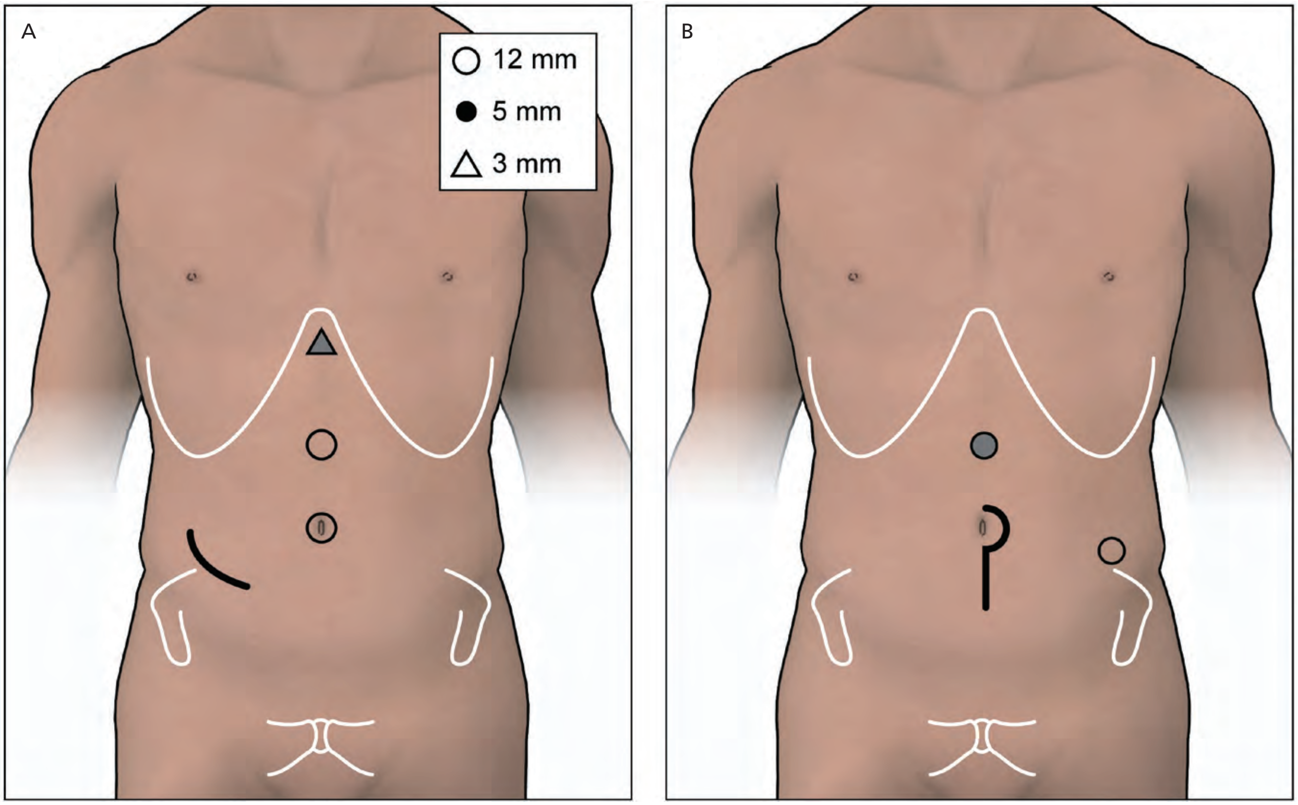

Figure 83.5 (A) Port placement for a right nephrectomy. The hand-port is indicated by the solid line. (B) Port placement for a left nephrectomy. The hand-port is indicated by the solid line.

obscures the renal hilum, the surgeon's use of their index finger can assist by palpating the renal artery. After sufficient exposure of the vein and artery is achieved, the endovascular stapler or clips are used to divide the artery, followed by the vein, while maintaining exposure of the renal hilum with the surgeon's hand.

At this point, the decision must be made whether to keep the adrenal or remove it with the kidney. On the right side, if the adrenal gland is to be taken with the kidney, the nondominant hand is used to retract the kidney laterally while the irrigator–aspirator is used to bluntly dissect the adrenal vein. After the short adrenal vein is exposed, it can be clipped and divided sharply. Once divided, a combination of energy-based dissection and finger-fracturing of the surrounding renal attachments expeditiously mobilizes the kidney and adrenal gland. While doing this, the surgeon is also simultaneously palpating and securing parasitic vessels feeding the tumor. Finally, the ureter is ligated and divided, completely freeing the specimen.

If there is adequate distance between the adrenal and renal mass, then salvage of the adrenal gland is appropriate. Dissection of the adrenal is performed by retraction on the adrenal with the off-hand and division of the adrenal gland from the kidney with energy-based dissection. The remaining portion of the nephrectomy is completed as described in the above section.

Finally, we recommend the use of a laparoscopically-deployed entrapment device for HALN. This helps protect the exposed incision from the unnecessary risk of tumor implantation.

Robot-assisted laparoscopic radical nephrectomy

Advantages/disadvantages

RLRN allows urologic surgeons with minimal laparoscopic skills to more easily transition open surgical techniques into a minimally invasive procedure. Disadvantages of this procedure include the lack of a haptic interface and the increased operating room costs imposed when using the robotic approach. Furthermore, operative time may be increased as a result of docking and undocking the robot [21]. Yet as robot-assisted surgery becomes more commonplace in urologic training programs, the role of RLRN will continue to expand. The following will describe the use of the da Vinci robotic system (Intuitive Surgical Inc., Sunnyvale, CA, USA) for a radical nephrectomy.

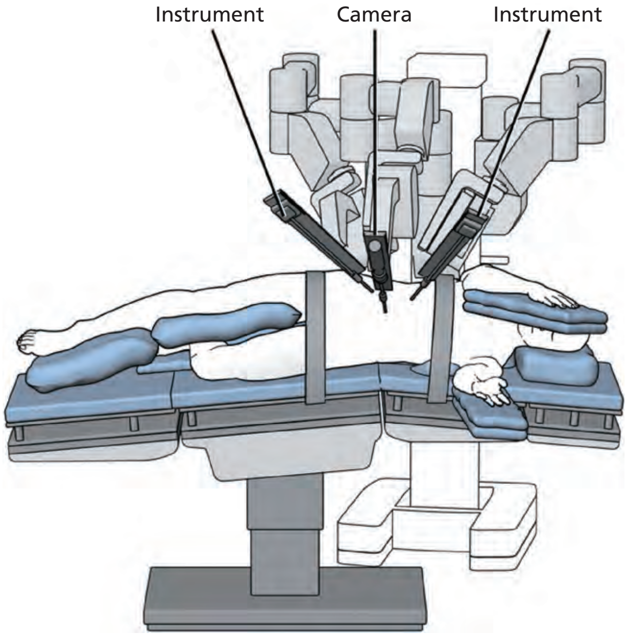

Figure 83.6 Robot docking position for a transperitoneal nephrectomy.

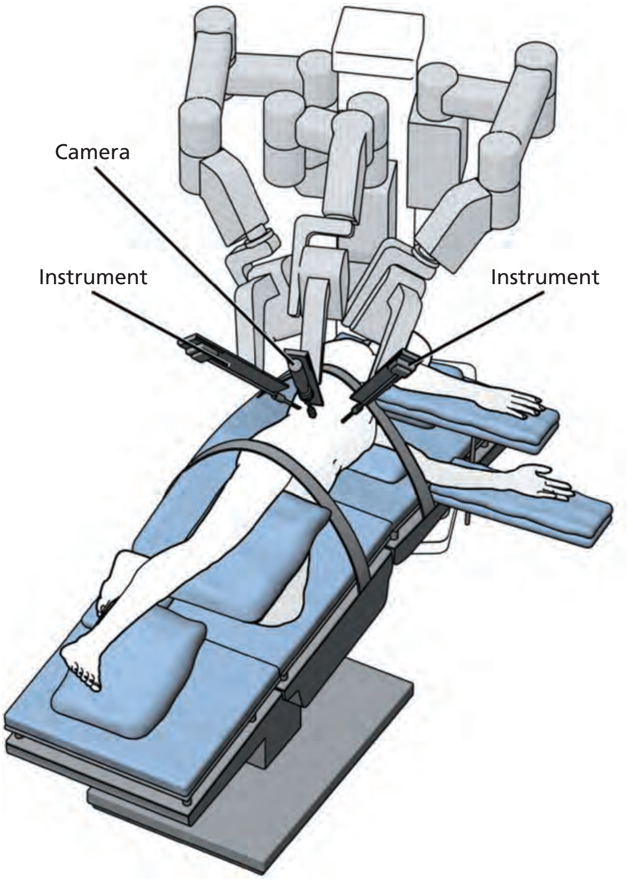

Figure 83.7 Robot docking position for a retroperitoneal nephrectomy.

Positioning

Robotic renal surgery can be performed both transperitoneally and retroperitoneally. For a transperitoneal approach, the robot is docked from the back of the patient at a 20° angle toward the head of the patient (Figure 83.6). When performing retroperitoneal robotic renal surgery, the robot is docked directly over the head of the patient (Figure 83.7). The patient is positioned in the modified lateral decubitus position as previously described for the transperitoneal approach with attention being paid to the arm ipsilateral to the affected kidney. If this arm is not positioned medial and cephalad, it could limit the movement of the subcostal robotic instrument.

Procedure

With the patient properly positioned, a pneumoperitoneum is achieved to a pressure of 15–20 mmHg. A 12-mm umbilical trocar is placed and the abdominal contents are inspected for adhesions and to rule out bowel injury after establishment of pneumoperitoneum. Two additional 8-mm robotic trocars are placed, each 8 cm from the umbilical trocar and from each other. A 12-mm assistant trocar is placed approximately 8 cm inferior to the umbilical trocar. An additional 5-mm assistant trocar is placed superior to the umbilical port if needed for organ retraction. When using the standard system, the trocars need to be spaced out further to avoid robotic arm collisions. When using the S or Si systems, the slimmer profile of the robot allows the trocars to be placed in closer proximity to each other.

Using the robotic Maryland forceps and electrocautery shears, the white line of Toldt is identified and incised sharply while the assistant is retracting medially on the bowel. Once the proper plane between the mesocolon and Gerota's fascia is established, much of the bowel mobilization can be done bluntly.

After adequate bowel mobilization, the ureter and gonadal vessels are exposed and lifted anteriorly to expose the psoas muscle. The assistant may retract anteriorly on the ureter, allowing the robotic surgeon use of both hands for additional dissection. For a right nephrectomy, the gonadal vessel needs to be swept medially in order to prevent inadvertent injury to or avulsion of the gonadal vein. Blunt dissection using both robotic arms for traction–counter-traction sweeping movements is performed when progressing cephalad along the psoas toward the hilum.

For a left nephrectomy, the spleen is mobilized as described for the pure laparoscopic approach. In the case of a right nephrectomy, the Kocher maneuver is performed exclusively with sharp dissection in the same manner as previously described.

With the lateral attachments of the kidney left in place, exposure of the hilum and renal vasculature can proceed. The Maryland dissector is used to retract the kidney laterally to place mild traction on the hilum for dissection. The bedside assistant may also be utilized for this. Electrocautery is often required to divide the dense lymphatic and fibrous tissue surrounding the renal artery. For large renal masses on the right, the robot may be helpful in dissecting an obscured renal artery from an interaortocaval approach. After the renal vasculature has been sufficiently exposed, the assistant inserts an endovascular stapler to divide the artery, followed by the renal vein. Alternatively, the assistant can ligate the vessels with clips. In addition, the robotic system allows the console surgeon to apply locking clips if the bedside assistant is unable to.

With the renal vasculature divided, an adrenal-sparing nephrectomy may be performed based on the location of the renal mass. After the kidney has been fully mobilized medially, it is freed from the surrounding renal fossa. At this point, liberal used of electrocautery and bipolar energy through the Maryland forceps can help minimize bleeding from parasitic vessels. Finally, with the kidney completely free within the abdomen, the pneumoperitoneum is slowly dropped and the renal fossa observed for several minutes to inspect for bleeding. The robot is undocked and the specimen is removed through an extraction site that was marked previously on the patient.

Laparoscopic, hand-assisted or robot-assisted nephroureterectomy

The indication for a nephroureterectomy is high-grade invasive urothelial carcinoma of the renal pelvis, proximal or mid ureter. The nephrectomy and proximal ureteral mobilization for a nephroureterectomy, regardless of the approach, are performed with the same positioning and port placement as for a radical nephrectomy. For a hand-assisted approach, an additional 12-mm port may be placed in either the right or left lower quadrant to aid in distal ureteral dissection. All specimens should be removed from the abdomen via an organ entrapment device and careful attention should be paid not to enter the collecting system during the laparoscopic part of the procedure due to the risk for tumor seeding [22]. Here we will review the various techniques for managing the distal ureterectomy and bladder-cuff excision.

Open technique

The open technique for distal ureterectomy allows the surgeon to offer the patient a minimally invasive nephrectomy and one incision to extract the specimen and manage the bladder cuff. The location of the incision is dependent on the technique used to perform the nephrectomy. Once the bladder is exposed and the anterior cystotomy is created, the ureteral orifice can be carefully excised. Suturing to close the orifice can help provide a handle for manipulating the intramural ureter during its dissection. Once excised, the specimen is removed *en bloc* and both cystotomies are closed. This approach to managing the bladder cuff is particularly useful in those patients with distal ureteral tumors in whom it is critical to have sufficient bladder-cuff excision [23].

For the hand-assisted approach, the distal ureterectomy can be completed using the incision for the hand port. If the hand port was placed in the midline, the incision may need to be extended inferiorly to gain adequate exposure of the bladder and ureteral orifice. Use of a Gibson incision for the hand port may obviate the need for a larger cystotomy as the bladder cuff may be excised extravesically. In this case, the ureter is dissected down to its intramural segment and the entire ureter and orifice are completely excised through a posterolateral cystotomy.

Transurethral excision of the ureteral orifice

When a transurethral excision is performed prior to the nephrectomy, the patient is positioned initially in the dorsal lithotomy position. A resectoscope and Collins knife are used to excise the ureteral orifice, essentially disengaging it from the bladder to allow for an easier distal ureterectomy without entering the bladder. Once completed, the patient is repositioned for the nephrectomy and ureterectomy part of the procedure. Some have reported higher rates of recurrence with this approach as the perivesical space is potentially exposed to tumor seeding through urine from the cystotomy [24]. In response to this concern, resection of the ureteral orifice *after* the nephrectomy and ureterectomy parts of the procedure have been completed has been proposed. This decreases the risk of potential tumor seeding from the upper tract after excision of the ureteral orifice [25].

Cystoscopically-guided transvesical bladder-cuff excision

In 1999, Gill *et al*. described a technique in which two 2-mm needlescopic ports are placed transvesically. The port ipsilateral to the affected side is used to place an endoloop around the ureteral orifice. Using a rigid cystoscope, a ureteral catheter is placed through the lumen of the endoloop and into the ureteral orifice. The cystoscope is removed and replaced with a resectoscope fitted with a Collins knife. The ureteral orifice and the intramural ureter are excised with the assistance of the contralateral needlescopic port. Once the bladder cuff is completely excised, the endoloop is tightened around the ureteral orifice while simultaneously withdrawing the ureteral catheter. At this point, the patient is repositioned for the nephroureterectomy [26].

Stapling of the distal ureter

For the distal ureter, after the nephrectomy, the patient is placed in the steep Trendelenburg position to allow improved exposure to the bladder. With the ureter dissected to the ureterovesical junction, an endoscopic stapling device with articulating head is placed across the distal ureter with a portion of the bladder incorporated within the jaws of the device [27]. After the intra-abdominal part of the procedure is complete, the specimen can be extracted, the trocar sites closed, and the patient repositioned in the dorsal lithotomy position. Using a rigid cystoscope, a ureteral catheter is placed into the ureteral orifice and advanced until resistance is met. A resectoscope fitted with a Collins knife is used to incise the roof of the intramural ureter over the ureteral catheter. Once the intramural ureter is exposed, a resectoscope and roller-ball are used to fulgurate the mucosa of the exposed ureteral tunnel. Although some concern has been raised regarding encrustation of the exposed staple line within the bladder, this has not been born out in the literature [28]. Others have suggested that laparoscopic stapling of the distal ureter and bladder cuff may lead to increased recurrence rates due to unrecognized tumor entrapped within the staple line. Matin and Gill demonstrated an increased local recurrence rate and decreased survival in those who underwent laparoscopic stapling with cystoscopic unroofing and fulguration of the distal ureter [29]. To address the issue of retained urothelium within the staple line, a pure laparoscopic approach has been described where the distal ureterectomy and cuff excision are performed extravesically. Complete laparoscopic distal ureter and bladder-cuff excision has the advantage of not requiring repositioning of the patient for cystoscopy. Once the entire intramural ureter is freed from the bladder, a tissue-loaded endoscopic stapler is used to excise the distal ureter, ureteral orifice, and bladder cuff [23]. Prior to engaging the stapler, the amount of bladder cuff being stapled should be noted and it should be ensured that the contralateral ureter and ureteral orifice are safely away from the intended staple line.

Robot-assisted laparoscopic distal ureterectomy

The robot-assisted approach to the distal ureterectomy and bladder-cuff excision has the advantage of being able to emulate the open technique. Initial experiences have described performing the nephrectomy and proximal ureteral mobilization using a traditional laparoscopic approach, then docking the robot for the distal ureterectomy [30]. Rha *et al.* have described a technique using 8-mm robotic ports placed through 12-mm ports to perform the entire procedure robotically with the patient in the lateral flank position and without redocking the robot. Once pneumoperitoneum is established, a 12-mm port is placed periumbilically. An 8-mm robotic port is placed along the lateral rectus border 4 cm inferior to the umbilicus, while the 12-mm port is placed in the midline between the xiphoid process and the umbilicus. The second robotic 8-mm port is then "telescoped" into the 12-mm port in the midline below the xiphoid process. Finally, a 12-mm assistant port is placed between the umbilicus and the pubic symphysis. Once the nephrectomy and proximal ureteral dissection is carried as far distally as possible, the robot arms are moved to different ports. The first arm is moved from the "telescoped" port to the port lateral to the rectus muscle. The robotic port is removed from the midline subxiphoid 12-mm port and then placed through the initial 12-mm assistant port originally placed between the pubic symphysis and the umbilicus. The camera is kept in the periumbilical port. From this configuration, the distal ureterectomy and bladder-cuff excision are performed. The cystotomy is sutured closed in two layers and the specimen is removed *en bloc* through an extended umbilical incision [31].

Results

Laparoscopic and hand-assisted radical nephrectomy

Since the original description of the laparoscopic nephrectomy in 1991, the minimally invasive approach to radical nephrectomy has gained wide acceptance throughout the urologic community and is now considered the treatment of choice for isolated renal masses not amenable to nephron-sparing surgery [32]. As urologic surgeons adopted the LRN, multiple series have been published touting its comparable oncologic outcomes to those for open radical nephrectomy (Table 83.1). The longest current series runs over 11 years postoperatively. The overall, cancer-specific, and recurrence-free survival rates at 10 years in this group were 65%, 92%, and 86%, respectively. From this series, 71% of renal masses were T1, 15% were T2, and 10% were T3a [32]. Several series have also demonstrated equivalent oncologic outcomes when comparing HALN to the open approach. Though these studies were limited by their retrospective nature, their results are nonetheless compelling [33–35]. Finally, with minimally invasive approaches to radical nephrectomy, patients benefit from less pain and shorter hospital admissions [33, 36]. Although RLRN should have similar outcomes to LRN, the data are not mature.

Table 83.1 Outcomes of hand-assisted laparoscopic (HALN), pure laparoscopic, and open radical nephrectomies.

Study	Patient number	Approach	Mean or median follow-up	Recurrence-free survival (%)	Cancer-specific survival (%)
Chung *et al.* [33]	54	HALN	47 months	91	94
Kawauchi *et al.* [34]	123	HALN	41 months	92	92
Miyake *et al.* [35]	63	HALN	38 months	85	92
Berger *et al.* [32]	73	Lap	11.2 years	86	92
Colombo *et al.* [46]	48	Lap	65 months	91	91
Permpongkosol *et al.* [47]	67	Lap	73 months	94	97
Hemal *et al.* [48]	132	Lap	56 months	87	88
Portis *et al.* [49]	64	Lap	54 months	92	98
Saika *et al.* [50]	181	Lap	40 months	91	94
Tsui *et al.* [51]	Stage I* 185	Open	47 months	NR	91
	Stage II* 57				74
Javidan *et al.* [52]	Stage I* 205	Open	64.5 months	NR	95
	Stage II* 53				88

*Based on 1997 TNM Staging criteria.

Laparoscopic and hand-assisted radical nephroureterectomy

The benefits of minimally-invasive approaches to upper tract urothelial cell carcinoma are similar to those seen with similar techniques used for renal masses with respect to patient discomfort and duration of hospitalization. The immediate concern with evaluating the efficacy of the nephroureterectomy lies ultimately in its oncologic outcomes. Several studies have detailed either long follow-up periods for cohorts of laparoscopic nephroureterectomies (LNUs) or have compared the laparoscopic to the traditional open approach.

Muntener *et al.* published their series of LNUs where 39 patients were followed postoperatively for a median of 74 months. Twenty-seven (69%) had a recurrence during the follow-up period. This group also had nine (23%) nonurothelial recurrences, while 11 patients died from their disease [37]. It was concluded that these results were similar to those reported with the open approach. Berger *et al.* also reported a total of 100 LNUs performed between 1997 and 2005 with a median follow-up of 7 years. The 7-year overall, cancer-specific, and recurrence-free survival rates were 50%, 72%, and 36%, respectively. Importantly, the nonurothelial 7-year recurrence-free rate for this group was 82% [38]. Both series, which document long-term follow-up, demonstrate comparable results to open nephroureterectomy.

In 2009, Simone *et al*. published their results from a prospective, randomized trial comparing laparoscopic to open nephroureterectomy. Forty patients were randomized to each group and followed for a mean of 41 months. Overall cancer-specific and recurrence-free survival were similar between the two groups. However, for T3 disease and high-grade tumors, the laparoscopic group had a poorer cancer-specific survival [39]. This is in contrast to an earlier study by Waldert *et al*. who documented similar survival rates between the laparoscopic and open approach on multivariate analysis, regardless of tumor grade or stage [40]. Clearly, further work is needed with respect to high-grade and stage tumors, though preliminary evidence appears promising.

Multiple approaches exist for managing the distal ureter for upper tract urothelial cell carcinoma (Table 83.2). In 36 patients, Matin *et al*. compared laparoscopically stapling the distal ureter after cystoscopically incising and fulgurating the intramural ureter to using needlescopic ports to excise the intramural ureter. They found that stapling was associated with higher positive margin rates as well as lower overall and recurrence-free survival. However, it should be noted that those who underwent laparoscopic stapling had confounding factors preventing the placement of needlescopic ports [29]. Brown *et al*. retrospectively compared four different techniques for distal ureteral management in their series of hand-assisted LNUs: cystoscopic disarticulation with a Collins knife; distal ureteral laparoscopic stapling; open distal ureterectomy; and *en bloc* hand-assisted distal ureterectomy with bladder-cuff excision. No cases of either a positive surgical margin or extravesical pelvic recurrence were noted in the 16 patients who underwent cystoscopic disarticulation, or in the three patients who received the open approach to the distal ureter. Two of the seven patients who received distal ureteral stapling were found to have positive surgical margins, though no pelvic recurrences were found. Finally, in the 29 patients who underwent hand-assisted *en bloc* distal ureterectomy, three positive margins and one pelvic recurrence were noted [41]. Both these studies illustrate the variety of ways in which to approach the distal

Table 83.2 Local recurrence and distant metastatic rates for different distal ureter management strategies.

Study	Distal ureter management	Patient number	Mean or median follow-up	Nonurothelial local recurrences (%)	Distant metastases (%)
Matin and Gill [29]	Lap stapling	12	23 months	8.3	25
Brown *et al.* [41]	Lap stapling	7	24 months	0	0
Hattori *et al.* [53]	Lap stapling	53	17 months	11	4
Matin and Gill [29]	CTBCE	36	23 months	5.6	8.3
Hattori *et al.* [53]	Open	36	31 months	10.1	2
Brown *et al.* [41]	Open	3	24 months	0	0
Shalhav *et al.* [54]	TUE	25	24 months	12	12
Brown *et al.* [41]	TUE	16	24 months	0	19
Wong and Leveillee [25]	TUE	14	8 months	0	0

CTBCE, cystoscopically-guided transvesical bladder-cuff excision; TUE, transurethral excision.

ureter, yet no clear conclusions can be made at this point.

Though the benefits of lymphadenectomy during radical cystectomy have been established, performing a lymph node dissection for upper tract urothelial cell carcinoma remains controversial. Lughezzani *et al*. reviewed data from a cancer registry and compared cancer-specific survival rates in those who underwent lymphadenectomy to those who did not. Specifically, they found no difference in cancer-specific survival between those who were pNx and pNo on multivariate analysis. One shortcoming of this study, however, is the nonstandardization of the patient population; the extent of lymph node dissection performed at each center was not documented [42]. This is in contrast to the study by Kondo *et al*. in a cohort of patients who underwent nephroureterectomies and in whom it was documented whether they received either complete or incomplete regional lymphadenectomies [43]. Regional lymph nodes were defined based on tumor location. Complete and incomplete lymph node dissections demonstrated a nonsignificant increase in cancer-specific survival within the entire group. However, when those patients with pT3–4 disease were subcategorized, both complete and incomplete lymph node dissections demonstrated a statistically significant improvement in cancer-specific survival. Finally, on multivariate analysis, complete lymph node dissection was a significant prognostic factor in those with pT3–4 disease, whereas incomplete lymph node dissection was not, suggesting that the extent of nodal dissection is important. These data are supported by a more recent multi-institutional study comparing pNx to pNo patients who underwent radical nephroureterectomy [44]. Although no cancer-specific survival benefit was conferred in those with a pT1 primary tumor, patients with pT2–4 primary tumors who underwent a lymphadenectomy were found to have significant improvement in cancer-specific survival.

Finally, the question remains of whether a lymphadenectomy may be adequately performed using minimally invasive techniques. Data comparing an open lymphadenectomy cohort for upper tract urothelial carcinoma to those who underwent laparoscopic lymphadenectomy demonstrated no difference in nodal yield or density [45]. Whether this will also be the finding with the robotic approach has yet to be determined. With growing support for performing routine lymphadenectomies in conjunction with radical nephroureterectomy, additional studies are needed to demonstrate oncologic equivalence of minimally invasive approaches to this surgical technique.

Conclusions

Significant advances have been made in the field of minimally invasive surgery and these have yielded impressive gains in patient convalescence, while providing sound, oncologic management for renal and urothelial malignancies. New advances in nephron-sparing surgery have further improved patient outcomes, while still providing the benefits conferred by laparoscopy. With the development of robotic technology, these advances can be utilized by those with less advanced laparoscopic skills, thus extending the reach of minimally invasive surgery to a greater number of patients.

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CHAPTER 84

Renal Surgery for Malignant Disease: Nephron-Sparing Surgery

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Introduction

Historically, open partial nephrectomy (OPN) was introduced for patients with imperative indications for nephron-sparing surgery like solitary kidney, renal dysfunction, or bilateral tumors. When laparoscopy initially emerged in 1991 for oncologic kidney surgery, malignant conditions were exclusively treated with radical nephrectomy. In 1993, Winfield was the first to describe laparoscopic partial nephrectomy (LPN) for benign disease [1]. Since then, LPN has undergone a continuous evolution and today the majority of clinical T1a (<4 cm) and many clinical T1b (4–7 cm) kidney tumors in high-volume centers are being treated with elective LPN [2]. Guidelines released by both the American Urological Association (AUA) and the European Association of Urology (EAU) recommend LPN as a standard of care for renal masses up to 7 cm [3, 4]. In experienced hands, the indications may even be expanded to patients at higher surgical risk and those who have anatomically more demanding tumors.

As the surgical steps have been mastered and the oncologic outcomes demonstrated to be comparable to those of OPN [5], the optimization of postoperative kidney function has increasingly become a focus of interest. Chronic kidney disease is a substantial concern in the general elderly population with comorbid conditions. Therefore, subjects undergoing kidney surgery for T1 tumors should, if oncologically acceptable, have as much parenchyma as possible preserved, irrespective of age [6]. While nephron-sparing surgery itself decreases long-term morbidity when compared to radical nephrectomy [7, 8], recent data have demonstrated that the length of perioperative ischemia is proportionally responsible for increased risk of acute postoperative renal failure and new-onset stage IV chronic kidney disease [2].

The minimally invasive laparoscopic and robotic approach allows for decreased postoperative pain, faster convalescence, and shorter length of hospital stay when compared to the open procedure. However, LPN and robot-assisted partial nephrectomy (RAPN), with their increased technical demands, require extensive experience and specialized skills.

Laparoscopic partial nephrectomy

Absolute indications

Bilateral kidney tumors and tumors in a functionally or anatomically solitary kidney represent an absolute indication for partial nephrectomy. While solitary kidneys are a challenge during the peri- and post-operative course, with special focus on fluid and electrolyte balance, controlled surgical and oncologic outcomes have been documented in several studies [9].

Relative indications

Conditions such as pre-existing renal dysfunction, metabolic syndrome, nephrotoxic drug intake (e.g. future need for chemotherapy), genetic predisposition to meta-

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chronous renal cell carcinoma (e.g. von Hippel–Lindau disease), renovascular disease, recurrent kidney stones, etc. create the risk for future kidney functional impairment. These clinical conditions constitute a relative indication for nephron-sparing surgery.

Elective indications

The widespread use of routine body imaging led to a significant increase in incidentally-diagnosed small renal masses (<4 cm). The term elective partial nephrectomy describes the resection of a localized unilateral kidney tumor with a healthy contralateral organ, and today represents the most common indication for nephron-sparing surgery.

Clinical scenarios

Clinical T1a tumors (<4 cm)

Initially, LPN was restricted to patients with tumors of 4 cm or smaller in size. The reality is that nephron-sparing surgery in this cohort is still underused, as many cT1a lesions are treated with laparoscopic radical nephrectomy in the community [10, 11]. This is due to the fact that LPN is a technically-demanding surgery, mainly due to the requirement for intracorporeal suturing under ischemia-related time pressure. However, availability of the requisite technical expertise, especially at centers of excellence, has made LPN a preferred treatment modality for many elective cases with cT1a tumors in the presence of a normal contralateral kidney. OPN and laparoscopic radical nephrectomy are now typically reserved for more complex cases and special clinical scenarios.

Clinical T1b tumors (4–7 cm)

Mature series describe 9–23% of tumors of 4–7 cm in size being treated with LPN [12, 13]. In a tertiary center, up to 60% of patients with cT1b tumors underwent elective partial nephrectomy [14]. Interestingly, the risk of dying from clinical T1b kidney cancer is similar, irrespective of whether patients undergo partial or radical nephrectomy. Leibovich *et al*. documented 5-year recurrence-free survival rates following partial and radical nephrectomy for cT1b tumors at 94% and 98%, respectively [15]. These larger tumors are typically more complex as they are more likely to be in proximity to functionally important structures, such as hilar vessels and the collecting system. However, several series have demonstrated similar outcomes when comparing LPN for cT1a and cT1b tumors, including similar operative efficacy (estimated blood loss, operative time, intraoperative complications, conversion rates), perioperative outcomes, and pathologic success rates (positive surgical margins, recurrences, etc.). Equivalent outcomes have also been documented when comparing LPN with OPN for T1a lesions [11, 15, 16]. These reassuring results, together with the technical improvements, are the rationale for the minimally invasive nephron-sparing approach for larger kidney tumors.

Expanding indications

Common techniques for partial nephrectomy, open or laparoscopic, employ warm ischemia by means of hilar vessel clamping. Once the renal hilum is clamped, every minute may count. Ischemia time is a limiting factor when it comes to more complex lesions. Finally, tumor size, tumor location, patient comorbidities, and the surgeon's experience determine whether surgery is performed with a minimally invasive or open approach.

Hilar tumors

Optimal preoperative planning involves thin-slice (1 mm) computed tomography (CT) imaging with three-dimensional (3D) reconstruction. Unlike tumors in other locations, careful hilar dissection is necessary to delineate which vessels directly supply the tumor, and therefore can be ligated, without causing collateral ischemic damage to normal healthy parenchyma. Intraoperative laparoscopic ultrasound is employed to delineate the tumor size, contour, proximity to collecting system, and circumferential scoring to achieve negative surgical margins. Finally, tumor dissection takes place in a lateral to medial direction, following the vessels in a parallel fashion. This is preceded by early control of any tumor-entering vessels, while preserving vital blood supply to the remaining parenchyma. Precise reconstruction with superficial stitches is mandatory as deep parenchymal suturing carries the risk of occluding the remaining vessels. Although perioperative data (estimated blood loss, operative time, and positive margin rate) as well as oncologic outcome are comparable with contemporary series, the close relation to relevant vascular structures and the pelvicalyceal system is reflected by the considerable number of postsurgical complications. The majority of cases (75–88%) require the repair of the collecting system, and in more than 20% of cases the postoperative course of hilar tumors is complicated by problems such as postoperative hemorrhage and urinary leakage, even in a center of excellence [17, 18].

Central tumors

Central tumors commonly invade the collecting system or the central renal sinus fat on staging imagery, and represent approximately 55–63% of cases in current series. While the central tumors were larger than the peripheral tumors in a series comparing 154 central with 209 peripheral kidney tumors, the estimated blood loss as well as overall complication rates were similar for the two groups. However, the central tumors were associated with a longer operative time, longer length of stay, more early postoperative complications (6% vs 2%, $P = .05$), and most importantly, longer warm ischemia time (34 min vs 30 min, $P < .001$) [19]. Another series confirmed the difference in tumor size (LPN: central tumors 3.2 cm vs peripheral tumors 2.5 cm, $P < .05$) but was unable to show any difference for the perioperative features [20]. Again, the surgeon's experience is of upmost importance.

Completely intraparenchymal tumors

Intraoperatively, this subset of lesions is exclusively detected by renal ultrasonography as the tumor reveals no exophytic component. They are completely covered by normal appearing parenchyma and are often in close proximity to central structures. With the aid of ultrasonography, the resection boundaries are marked on the kidney's fibrotic capsule. In nearly all cases, the resection opens the collecting system [21], resulting in a cuneiform tissue defect. This is one of the few occasions a preprepared hemostatic Surgicel bolster helps to fill the parenchymal tissue gap, as described later.

Obesity

The crucial issues in the obese patients are proper positioning and trocar placement. The best possible padding is extremely important because these patients are at increased risk of rhabdomyolysis. The large body volume increases distances. Therefore, trocars have to be shifted laterally and the use of bariatric instruments is required to assure sufficient reach. Studies comparing LPN with OPN in obese patients report that LPN affords a shorter operative time (186 min vs 266 min), decreased warm ischemia time (26 min vs 44 min), lower estimated blood loss (300 mL vs 450 mL), and fewer intra- and post-operative complications (20% vs 50%) ($P < .05$ for all) [22].

Solitary kidney

Partial nephrectomy for a tumor in a solitary kidney is challenging irrespective of the type of approach. The lack of functional reserve due to the absent contralateral kidney, with potentially detrimental outcome in case of perioperative problems, clearly indicates the need for referral of such patients to experienced centers. Only established teams, including surgeons, anesthesiologists, and potentially intensive care providers, can assure successful outcome. In an early series, LPN revealed, even in patients with smaller tumors, a longer warm ischemia time (29 min vs 21 min, $P = .003$), more intraoperative complications (17% vs 1%, $P < .001$), and more postoperative complications (43% vs 24%, $P = .02$) when compared to OPN [9]. The duration of warm ischemia time and complication rate remain critical issues in other series as well [23, 24]. However, newer approaches, like the established early unclamping technique [25] or the development of clampless techniques, are promising in experienced hands. However, the threshold for intraoperative conversion to open surgery should definitively be lower in patients with a solitary kidney.

Multiple ipsilateral tumors

In view of the potential for contralateral recurrence, nephron-sparing surgery is the preferred treatment for patients with multiple, small ipsilateral tumors. The limiting factor, besides volume of remaining healthy parenchyma, is the warm ischemia time [26]. A detailed imaging study provides the necessary information to establish an efficient resection strategy. The procedure starts with the clampless resection of the simplest lesion. Hilar clamping is reserved for the resection of more complex masses. Ideally, only one or two resections have to be performed under warm ischemia, followed by a reasonable extent of reconstruction. Alternatively, all tumors are resected *en bloc*. This requires their presence in closest relation in order to avoid the sacrifice of significant amounts of healthy parenchyma. Based on the limited oncologic outcome data available, LPN combined with cryotherapy represents another option for a select group of patients [27].

Previous ipsilateral kidney surgery

In their feasibility analysis, Turna *et al*. emphasized that for all of their 25 cases, a meticulous adhesiolysis was paramount to successful completion [28]. Especially with a retroperitoneal approach, extensive digital dissection prior to balloon dilatation was necessary. In order to avoid major vascular complications, detailed hilar dissection within potentially dense adhesions was omitted. Subsequently, hilar occlusion was performed with the use of a Satinsky clamp instead of bulldog clamps.

Multiple renal arteries

In the presence of multiple hilar arteries, hilar Satinsky cross-clamping controls the major blood supply, while distant polar arteries should be individually dissected, allowing for selective bulldog clamping [29]. This setting underlines the need for optimal preoperative imaging studies. However, the surgeon must remain vigilant for potentially undetected vessels.

Cystic tumors

LNP for radiologically suspicious cystic tumor requires considerable caution. The procedure is technically more challenging due to the substantial risk for inadvertent cyst rupture and cellular spillage. Spaliviero *et al*. compared 50 patients with cystic kidney lesions to 50 consecutive patients with a solid renal mass. Both cohorts underwent uneventful LPN with similar perioperative outcomes, in particular no positive surgical margins or cystic rupture. However, one patient with an initial cystic lesion had a recurrence in the retroperitoneum at 1 year [30].

Surgical technique

Access

The surgical access to the kidneys can be achieved retro- or trans-peritoneally. Historically, the lumbotomy takes the extraperitoneal approach. Retrospective outcome studies investigating both of the minimally invasive accesses available demonstrate that the retroperitoneoscopic approach offers decreased operative time, lower estimated blood loss, faster time to resumption of a regular diet, and shorter length of stay, with similar warm ischemia time [31]. In addition, the retroperitoneoscopic approach offers the advantage of isolating any hemorrhage or urine leakage from the peritoneal cavity. This may be a benefit for particular medical conditions, like advanced liver cirrhosis [32]. However, a prospective randomized comparison of 102 patients revealed only a quicker hilar control and shorter operative time with retroperitoneoscopy, while all other patient outcomes were similar for both approaches [33]. We favor the transperitoneal approach because it offers more familiar landmarks, a larger working space with consecutively greater versatility of instrument angles, and most importantly, technical ease of intracorporeal suturing. The full renal mobilization allows the kidney to be rotated as required to provide optimal exposure of any mass regardless of its location. In addition, it offers enough space to place the Satinsky clamp and therefore avoids the time-consuming placement and removal of individual bulldog clamps. However, the retroperitoneoscopic route is an option in patients with expected severe adhesions due to multiple previous abdominal surgeries or in morbidly obese patients. The minimally invasive urologist should be familiar with both approaches and the final choice should be based on patient anatomy, the procedure to be performed, and the surgeon's preference [34].

Port placement for the laparoscopic approach

Depending on surgeon preference, three to five trocars can be employed routinely for LPN. While the three-port method requires the use of bulldog clamps, five trocars allow the introduction of a retractor and a Satinsky clamp. From our experience, we prefer the use of five trocars because this offers the safest and most efficient access (Figures 84.1 and 84.2).

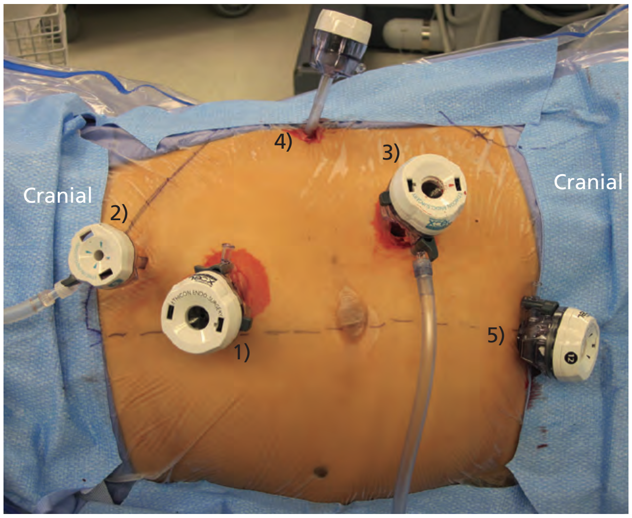

Figure 84.1 Left laparoscopic port placement (upper pole lesion). 1, 12-mm camera port; 2, 5-mm left-hand working instrument; 3, 12-mm right-hand working instrument; 4, 5-mm assistant port; 5, 12-mm port for Satinsky clamp.

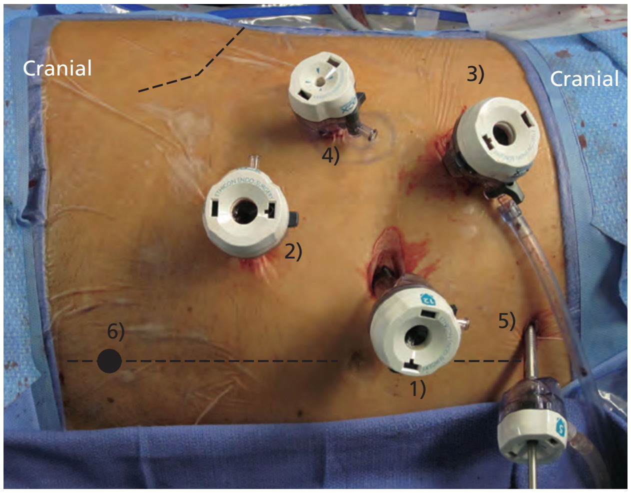

Figure 84.2 Right laparoscopic port placement (lower pole lesion). 1, 12-mm camera port; 2, 12-mm left-hand working instrument; 3, 12-mm right-hand working instrument; 4, 5-mm assistant port; 5, 5-mm port for liver retractor; 6, position of Satinsky clamp.

Surgery step-by-step

The colon is widely mobilized from Gerota's fascia so that it falls off the kidney medially without the need for constant retraction. Caudal to the lower pole of the kidney, the ureter and gonadal packet are lifted off from the psoas muscle. Dissection proceeds cephalad along these structures on the anterior surface of the psoas muscle until the renal vein is identified. The hilar vessels are carefully dissected *en bloc*. Except for the renal fat immediately over the tumor, the kidney is completely mobilized and defatted within Gerota's fascia. With a flexible 7-MHz ultrasound probe, the tumor margin is circumferentially identified and the future resection line scored with electrocautery, with consideration for an adequate margin of normal renal parenchyma around the tumor. Approximately 30 min prior to clamping, 12.5 mg of mannitol and 10 mg of furosemide (Lasix) are given. With a laparoscopic Satinsky clamp brought in through a 12-mm trocar placed in the midline suprapubic region, the renal hilum is clamped *en bloc*. The bloodless conditions allow for identification of the healthy parenchymal margin, and the tumor is then excised with cold Endoshears (Figure 84.3) and finally placed in an Endobag. During the resection, any large vessels or collecting system tributaries can be prospectively clipped with Hem-o-lok clips (Weck Closure System, Research Triangle Park, NC, USA) (Figure 84.4). Next, one to several horizontal running mattress sutures (Vicryl 2-0 on a CT-1 needle) are used to ensure hemostasis and to repair any collecting system violations (Figure 84.5). The sutures can be individually tied or a Hem-o-lok clip can be placed on each end to secure the suture and prevent it from pulling through. Retrograde injection of diluted methylene blue through a preoperatively inserted ureteral stent confirms water tightness.

After performing the horizontal mattress sutures, the parenchymal defect is covered with FloSeal (gelatin matrix thrombin sealant; Baxter Healthcare, Deerfield,

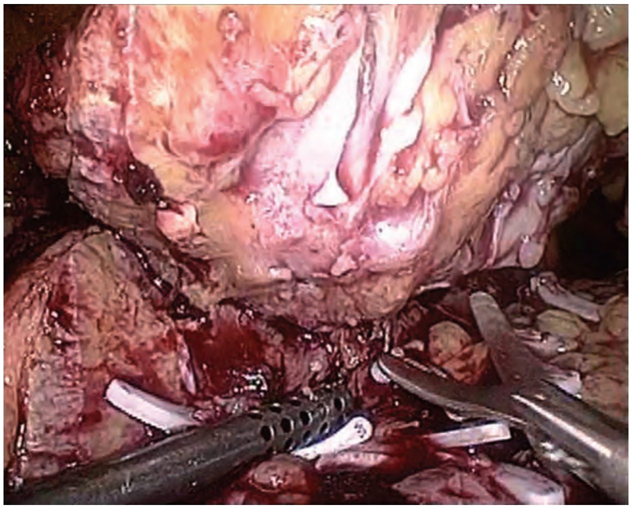

Figure 84.4 While sharply dissecting the fragile parenchyma, presenting vascular or other solid structures (collecting system) are secured with Hem-o-lok clips. With suction pressing the ancient tumor bed downwards, the dissection upwards along the posterior contour can be eased.

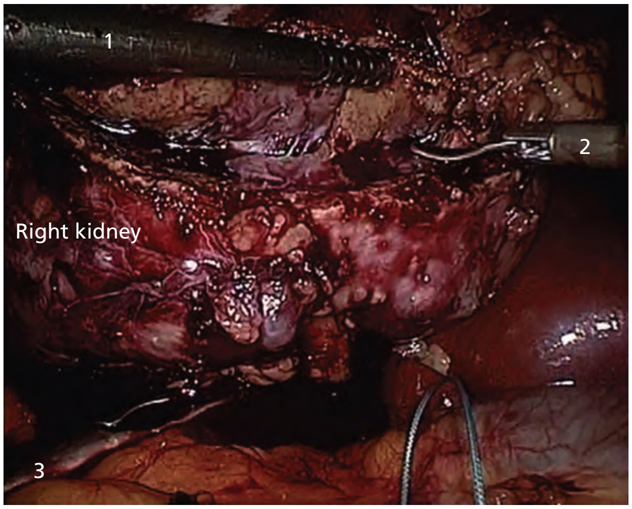

Figure 84.3 Suction in the left hand allows the tissue to be lifted up, nicely presenting the cutting edges. Tumor resection is performed with cold Endoshears in the bloodless operative field, respecting a margin of healthy parenchyma around the lesion. 1, Suction; 2, Endoshears; 3, Satinsky clamp.

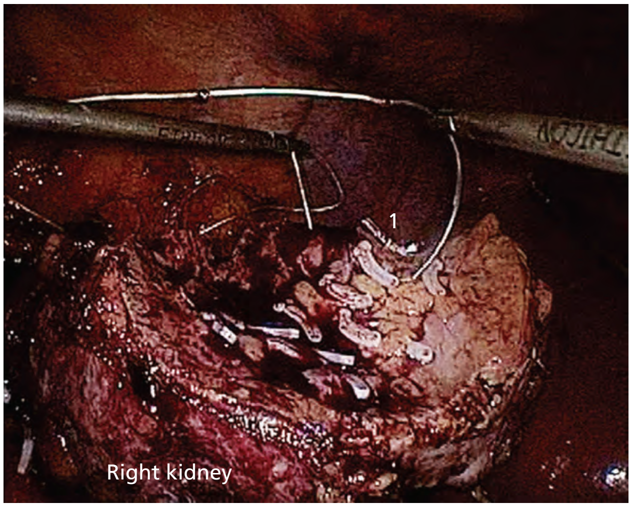

Figure 84.5 Horizontal running mattress sutures typically start outside the resection bed. The thread is anchored with a Hem-o-lok clip (1). The stitch passes horizontally just below the clips applied during the previous resection. One hand guides the needle while the other hand maintains traction on the suture.

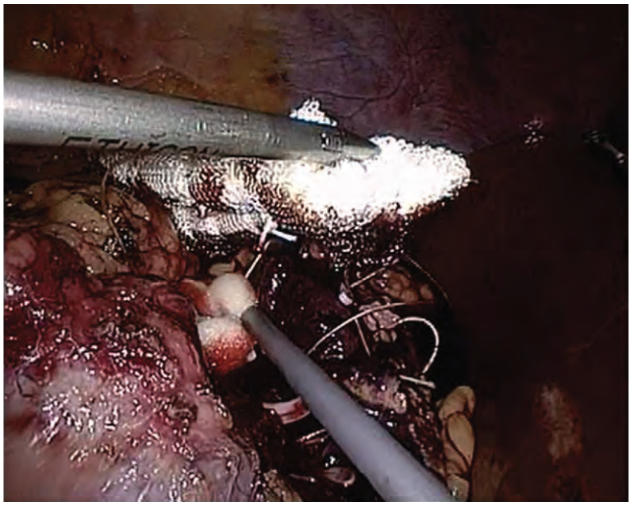

Figure 84.6 Substantial parenchymal defects are first filled with the hemostatic tissue sealant FloSeal, and finally covered with the a preprepared Surgicel bolster.

IL, USA), a biologic hemostatic tissue sealant, and an unfolded Surgicel gauze. More substantial renal parenchymal defects are first filled with the same tissue sealant and then covered with a preprepared Surgicel bolster (Johnson & Johnson, New Brunswick, NJ, USA) (Figure 84.6). If a bolster is used, several more horizontal mattress sutures are used to approximate the parenchymal borders to guarantee adequate tissue compression. Eventually, the entire resection site is covered with a layer of fibrin glue (Tisseel; Baxter Healthcare). After confirmed hemostasis, 12.5 g of mannitol and 10–20 >mg of furosemide are given, and the Satinsky clamp opened and removed. The Endobag with the specimen is retrieved and a Jackson–Pratt drain placed, mostly through the 5-mm assistant port in the flank.

Hemostasis

For this crucial step, several strategies have been advocated. However, we strongly emphasize that advanced LPN necessarily requires the performance of unconditional intracorporeal free-hand suturing. In addition, energy sources, selective use of surgical clips, adjunctive hemostatic/sealant agents [35, 36], and bolsters are individually used in addition.

Hilar control

There are two ways to clamp the blood supply prior to beginning the tumor resection. The application of laparoscopic bulldog clamps on the hilar vessels requires a meticulous vascular skeletonization. In addition, several technically challenging maneuvers are necessary to clamp and unclamp the circulation, and there is still the risk of bleeding due to unidentified accessory hilar vessels. Therefore, we favor the use of a laparoscopic Satinsky clamp, introduced with or without a 12-mm suprapubic port, cross (*en bloc*)-clamping the hilum. The accessory port is out of the surgeon's working instrument range and this allows for easy handling of the Satinsky clamp. However, both techniques, bulldog and Satinsky clamp, provide sufficient visualization for exact tumor excision, pelvicalyceal repair, and hemostatic parenchymal suturing in a bloodless field. In addition, the artery-only clamping technique has been established in order to decrease the renal damage during warm ischemia. However, renal functional improvements could not be demonstrated in an animal model and the impaired visualization with the increased risk of hemorrhage has only lead to a limited application of this approach [37, 38].

Renal ischemia

Huang *et al*. demonstrated that 26% of our surgical kidney cancer patients had a certain degree of impaired renal function at baseline. In addition, patients undergoing radical nephrectomy are more likely to develop new-onset chronic kidney disease compared to patients undergoing partial nephrectomy [39]. Because all the kidney's metabolic activities require oxygen, the renal cortex is extremely sensitive to ischemia. With the arterial blood supply clamped, energy sources providing structural and functional cellular integrity break down [40, 41]. Subsequently, failure of the cellular membrane transport mechanisms leads to cellular death. While select small, peripheral, exophytic kidney tumors are resectable with an unclamped technique, deep parenchyma invading lesions are most commonly performed using some form of hilar occlusion. The safe duration of ischemia remains controversial. Experimental studies describe the beginning of renal damage and cellular degeneration of the nephron after 20–30 min of clamping. Ischemia itself acts on the physiologic part of the parenchyma and is not the only prognostic factor impairing the renal function. The pure extent of remaining healthy kidney parenchyma depends directly on the tumor size as this defines the resection widths. In addition, extensive reconstructive and hemostatic suturing has a deleterious effect on the remaining healthy parenchyma. Thompson *et al*., recently showed in a large series ($n = 458$) of patients with solitary kidneys, that those managed with warm ischemia are significantly more likely to develop acute renal failure in the postoperative period as well as new-onset stage IV chronic kidney disease during follow-up compared to those managed without hilar clamping [42]. This study indicated that an upper limit of 25 min warm ischemia time should not be exceeded. It is crucial to know that every 5 min of warm ischemia time is associated with a

$2.2\,\text{mL/min/}1.73\,\text{m}^2$ decline in glomerular filtration rate [9]. According to an expert panel, warm ischemia time is the strongest modifiable surgical risk factor for postoperative kidney disease and should therefore be kept to less than 20 min [38]. For patients with complex tumors most probably requiring ischemic times longer than 20–30 min, strong consideration should be given to hypothermic conditions, allowing for longer clamping. Laparoscopically, the kidney can be cooled with ice slush on the organ's surface, instillation of cold saline through a retrograde ureteral catheter, and/or intra-arterial perfusion of cold saline/lactated Ringer's [43–45].

While for OPN, cold ischemia is the method of choice, warm ischemia via hilar cross-clamping is the method widely used in the minimally invasive setting. This technique has developed to allow early unclamping, with a dramatic improvement regarding warm ischemia time [25]. This development was necessary because larger series have documented critically long warm ischemia times in the 23–35 min range [12, 13, 37, 46]. With the early unclamping technique, cold resection is performed under warm ischemia time. Major vessels and collecting system parts are successively closed with Hem-o-lok clips. After the tumor resection, a single hemostatic horizontal running mattress suture is performed within the resection bed, below the previously applied clips. Thereafter, the Satinsky clamp is opened briefly to reperfuse the kidney and evaluate hemostasis. If the bleeding is found to be acceptable, the Satinsky clamp is removed. Individual areas of hemorrhage are controlled with additional suturing, allowing for adequate visualization to guarantee optimal further vessel ligation, collecting system repair, and renorrhaphy with/without a bolster. In our series, this technique halved warm ischemia time from a median of 31.9 min to 14.4 min [12]. Although estimated blood loss increased, the rate of postoperative hemorrhage decreased. This is likely due to identification of transected vessels in the reperfused resection bed. Further attempts focusing on zero ischemia time have been successfully developed in our institution and have been demonstrated at several live surgery symposiums. However, this latest technology requires further refinement before it can be implemented in general practice.

Manual/instrumental compression of renal parenchyma is a great option in open or hand-assisted surgery, mainly for polar lesions. In select cases (e.g. polar lesions), it even allows complete omission of hilar clamping. However, the hilar vessels should always be accessible for emergent clamping. Excessive compression potentially leads to tissue trauma; therefore, bowel clamps, tourniquets or other instruments applicable in the minimally invasive setting have to be used carefully. Due to the reduction in time sensitivity, parenchymal compression potentially allows a larger cohort of surgeons to perform LPN.

There is ongoing contention regarding the impact of intermittent kidney perfusion by sequential clamping and unclamping in the course of a partial nephrectomy. The data from animal studies are conflicting [47, 48]. Additionally, ischemic preconditioning, extensively studied for liver surgery, has never been analyzed for human kidneys [49, 50]. Therefore no evidence-based general statement can be made about what the best action is if there is substantial, uncontrolled hemorrhage from the resection bed after unclamping. In our experience, we prefer a limited reclamping to achieve the necessary visualization for precise hemostasis. The conversion to open surgery is definitively a valuable option. However, the time requirement to perform the access has to be taken into the time considerations.

Contemporary outcomes

In short, LPN evolved from a burgeoning procedure to the standard of care for the majority of renal masses, recommended by the established American and European guidelines of urology [3, 4]. Despite increasing tumor complexity, warm ischemia time, complication rate, postinterventional kidney function, and oncologic outcomes have significantly improved and are today comparable to OPN. The fact that radical nephrectomy for the treatment of small renal masses is still widely performed reflects the required surgical skills for LPN [10]. However, at tertiary centers of expertise, LPN will likely replace OPN in the near future as the reference standard treatment for the majority of patients with a surgical renal mass.

Comparison between open and laparoscopic partial nephrectomy

Compared to OPN, the earlier gold standard of care, LPN was initially performed on smaller and more peripherally located tumors. This partially explains its lower blood loss and shorter operative time. Of course, the minimally invasive approach offers shorter hospital stay followed by faster convalescence. However, patients undergoing LPN revealed more postoperative complications, conversions to radical nephrectomy, longer warm ischemia time, and a higher postoperative hemorrhage and reintervention rate. This is confirmed by the findings of a recent meta-analysis of the AUA [4]. On the other hand, intraoperative complications, positive surgical margin rates, oncologic and functional 3-year data were similar, as shown in the comparison of LPN and OPN performed in 1800 patients with a single renal tumor ($<7\,\text{cm}$) at major centers with greatest expertise [51].

Table 84.1 Laparoscopic (LPN) versus open partial nephrectomy (OPN): perioperative data.

	Number of patients		Tumor size (cm)		Operative time (min)		Estimated blood loss (mL)		Warm ischemia time (min)		Length of stay (days)	
	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN
Gill *et al.* [51]	771	1028	2.6†	3.3†	201†	266†	300†	376†	30.7†	20.1†	3.3†	5.8†
Marszalek *et al.* [46]	100	100	2.8	2.9	85†	150†	15.4%Φ	13.6%Φ	23†	31†‡	5†	7†
Permpongkosol *et al.* [13]	85	58	2.4†	2.9†	225†	276†	436.9	427.7	29.5†	48†	3.3†	5.4†
Lane *et al.* [9]*	30	169	2.8†	3.8†	205†	264†	200	300	29†	21†	3†	5†

*Solitary kidney population.

†Identified as statistically significant (P<.05) in intrastudy analysis.

‡Cold ischemia time.

ΦPercent decline in hemoglobin.

Table 84.2 Laparoscopic (LPN) versus open partial nephrectomy (OPN); complications.

	Number of patients		Intraoperative complications (%)		Postoperative complications (%)		Urine leakage (%)		Postoperative-hemorrhage (%)		Renal loss (%)	
	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN	LPN	OPN
Gill *et al.* [51]	771	1028	1.8	1.0	18.6†	13.7†	3.1	2.3	4.2†	1.6†	2.1	0.4
Marszalek *et al.* [46]	100	100	10†	3.0†	14	19	4	2	6	1	–	–
Permpongkosol *et al.* [13]	85	58	3.5	3.5	3.5	22.4	1.2	1.7	2.4	5.2	–	–
Lane *et al.* [9]*	30	169	17†	1.2†	43†	24†	10	4.7	10	5.9	3.3	0

*Solitary kidney population.

†Identified as statistically significant (*P*<.05) in intrastudy analysis.

With increasing experience and technical development, LPN outcomes have significantly improved. In their consecutive single-surgeon series, Gill *et al*. showed that despite the targeted tumors progressively increasing in complexity over time, warm ischemia time, and overall postoperative and urologic complications decreased remarkably [12].

Tables 84.1 and 84.2 summarize perioperative data and complication rates of four LPN versus OPN comparison series.

Positive surgical margins

The central tenet of any oncologic renal surgery is the complete resection of tumor along with a margin of healthy parenchyma. In their large cohort of OPN, Yossepowitch *et al*. found 5.7% patients (77 of 1344 patients) to have positive surgical margins on final pathology. All were treated expectantly. The recurrence-free survival at 10 years was 93% both for patients with positive and negative surgical margins. The investigators concluded that positive surgical margins in partial nephrectomy specimens do not uniformly indicate an adverse prognosis and therefore, select patients with a positive surgical margin can be offered vigilant monitoring without compromising long-term disease-free survival [52]. In comparison, larger LPN series, each including more than 400 patients, report positive surgical margin rates between 0.8% and 2.4% [12, 35, 51, 53, 54]. However, we strongly advocate several intraoperative frozen sections from the tumor bed. Besides the medicolegal aspect, this eventually helps to estimate the recurrence risk in case of unexpected positive surgical margins on the final pathology report.

Survival data

Care must be taken when comparing long-term survival data from different series because of the heterogeneous cohorts. Lane *et al*. reported a series with a minimum of 7 years of follow-up (77 LPN, 310 OPN). For pT1a tumors, the reported 7-year recurrence-free survival after LPN and OPN was 93% and 95%, respectively (*P* = .7), and disease-specific survival was 95% and 95%, respectively ($P = 1.0$). For pT1b tumors, the 7-year recurrence-free survival after LPN and OPN was 82% and 95% ($P = .17$), and disease-specific survival was 82% and 96%, respectively ($P = .12$). In the multivariable setting, increasing age, comorbidities, hypertension, 5-year treatment failure probability based on the Kattan nomogram [55], and preoperative renal impairment, but not surgery type (LPN vs OPN) and tumor size, were significant predictors of mortality. Multiple studies with shorter follow-up support these findings [5, 13, 15, 46, 51, 56].

Robot-assisted partial nephrectomy

Being well established for the treatment of prostate cancer in the small pelvis, RAPN has become a rapidly emerging approach for the treatment of kidney cancer [57–61]. The wrist function of the robotic arms provides an advantageous angle to perform the crucial resection in the depths of the renal parenchymal bed and facilitates the intracorporeal suturing.

However, there are some technical considerations. Once the robot is docked, table rotation becomes impossible. Therefore, depending upon tumor location and consecutive trocar placement, the initial part of the intervention may be performed using standard laparoscopy with the use of the robot only for tumor resection and renal reconstruction. The majority of authors prefer a flank position with the table moderately flexed [62–64]. Because the robot-assisted procedure requires additional trocars compared to standard LPN, this allows for better spacing of instruments and fewer clashing incidents of the robotic arms. The exchange of robotic instruments and technical robotic failures in the course of warm ischemia remain critical issues. The port-in-port technique of RAPN, wherein the 8-mm robotic ports are inserted through two standard 12-mm laparoscopic ports, represents a valuable option in the initial learning curve to avoid wasting precious time in case of an emergent conversion to conventional LPN. No new port placement is required because CT-1 or CT-X needles may be directly introduced through the 12-mm ports in place once the robot is undocked [64].

Port placement for the robot-assisted approach

As mentioned, the entire procedure may be performed with the aid of the robot or the operation may be started using standard laparoscopy with utilization of the robotic assistance only for tumor excision and renorrhaphy. However, the timing of docking the robot must be considered because with the robot docked, table rotation becomes impossible.

For institutions with a three-arm robot configuration, four to five trocars are necessary: a 12-mm periumbilical camera port, a 8-mm subcostal robotic trocar in the anterior axillary line, a 8-mm robotic trocar in the posterior axillary line one cross finger above the iliac crest, and one 12-mm assistant trocar in the low midline to allow for passage of sutures, bulldog clamps, suction, or retraction. If deemed necessary, an additional 12-mm subxiphoid trocar may be inserted for retraction or passage of bulldog clamps from a different angle. Using a four-arm configuration involves five to six trocars. The same trocar configuration can be used as demonstrated for the standard laparoscopic approach (see Figures 84.1 and 84.2), but the robotic trocars should be shifted slightly to avoid clashing of the three arms. The table-side assistant is responsible for clamping the renal hilum, providing suction and retraction, delivering and cutting sutures, and clip placement.

In available preliminary retrospective studies, RAPN has demonstrated equal [64] or even improved [65] perioperative outcome compared to LPN. However, feasibility is by far not the most important endpoint. In addition, the robot-assisted approach is associated with increased costs and cosmetic inferiority due to the need for additional port placement. Therefore, to determine the true value of RAPN for treatment of renal cell carcinoma, prospective randomized studies with longer follow-up are mandatory.

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CHAPTER 85

Laparoscopic and Robotic Adrenalectomy

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Introduction

Since it was described in 1992 [1], laparoscopic adrenalectomy (LA) has become the standard of care for a variety of adrenal lesions in many centers around the world. Multiple studies have reported significant advantages with the laparoscopic approach when compared with the traditional open approach. This minimally invasive approach offers patients less postoperative pain, a shorter hospital stay, a faster return to normal activities, and a better cosmetic result.

In the past decade, robotic technology has been introduced to assist laparoscopic procedures. With a three-dimensional (3D) display to enhance depth perception and instruments containing a "wrist" joint to improve dexterity, robot assistance may offer advantages over standard laparoscopy, potentially reducing the technical complexity of the procedure and enabling less experienced surgeons to deliver minimally invasive surgery to their patients.

In this chapter, the current techniques and results of LA and robot-assisted LA will be reviewed in detail. Recent developments, such as laparoendoscopic single site (LESS), partial adrenalectomy, and ablative techniques, are also discussed.

Indications

LA is a safe and effective method for removal of most adrenal lesions. Current indications for LA include functioning adrenal lesions, such as aldosteronoma, pheochromocytoma, and androgen/estrogen, glucocorticoid-producing adenomas. Occasionally, symptomatic adrenal cysts and myelolipomas may be removed laparoscopically. Bilateral LA may also be performed in patients with bilateral adrenal hyperplasia (Cushing syndrome or disease). Nonfunctioning adrenal lesions larger than 4–5 cm or tumors that have shown growth in size on serial imaging may also be excised laparoscopically.

The use of laparoscopy in the management of larger malignant masses is somewhat controversial. The lack of a true capsule around the adrenal gland greatly increases the risk of local invasion of these highly aggressive tumors. This makes complete excision and adherence to basic oncologic principles a difficult task, even during open surgical approaches. It is not surprising that long-term survival rates for any surgical approach have been poor, especially when coupled with the lack of effective chemotherapeutic agents.

In light of these difficulties, many surgeons advocate an open approach to known adrenal malignancies or for large lesions (>8 cm). In spite of these fears, there have been multiple reports of effective and complete laparoscopic surgical excision of malignant masses [2, 3]. Prospective, randomized controlled trials are lacking, however, and may be slow in coming because of the relative rarity of these tumors (0.3% of all cancers). LA for adrenal metastases has also been reported to have excellent outcomes in select patients [4, 5].

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Contraindications

General contraindications to a laparoscopic approach include those patients with an uncorrected coagulopathy, peritonitis, intestinal obstruction, and severe cardiopulmonary disease. The list of contraindications for LA continues to shrink as experience with laparoscopic surgery matures. Locally advanced tumors with obvious extension to surrounding structures or those with venous involvement are not candidates for laparoscopic excision and should be resected with an open approach.

Adrenal cortical carcinoma (ACC) was previously considered to be a contraindication for LA because of the concern for tumor clearance and intraoperative spillage, but recent publications suggest that laparoscopic and open approaches for noninvasive ACC have comparable outcomes when the principles of oncologic surgery are respected [2–4, 6, 7]. Although the maximal size of an adrenal lesion suitable for LA is still debated, most surgeons agree that tumor sizes of 12–14 cm represent the upper limits of LA [3]. However, it has to be noted that the overall morbidity and mortality is independent of the size of the tumor [8]. In summary, with sufficient laparoscopic experience there appears to be no size limit to the feasibility of LA.

Malignant pheochromocytomas should also be approached cautiously. Although the resection of malignant pheochromocytomas by laparoscopic approach has been reported, there are still insufficient data on the long-term follow-up of these patients [3, 7, 9, 10].

Obesity has been suggested to be a relative contraindication to a laparoscopic approach to the adrenal gland. Indeed, early series have shown a higher rate of complication (especially minor) in patients with an elevated body mass index (BMI). While more recent investigators have noted that obesity is associated with longer operating room times and slight increases in complication rates, most authors feel that obese patients are easily managed as the surgeon gains operative experience and advances along the learning curve [11].

Finally, significant previous abdominal surgery can be a relative contraindication to transperitoneal laparoscopy if adhesions are so dense as to create an unacceptably high risk of inadvertent enterotomy. In this instance, the surgeon can opt for a retroperitoneal approach, either through a standard flank incision or through retroperitoneal laparoscopy [12].

Preoperative management

A complete step-by-step discussion of the evaluation of a patient with an adrenal lesion is beyond the scope of this chapter. Clearly, each patient requires an assessment of any lesion from a radiologic perspective as well as a full metabolic evaluation.

A complete endocrinologic assessment will entail measurement of serum electrolytes, serum hormone levels, serum catecholamines, urine studies for catecholamines and their metabolites, and urine levels of steroid hormones and their metabolites. In addition, stimulation studies, such as low- and high-dose dexamethasone suppression tests, and plasma renin activity can also be applied when appropriate.

Patients with a functioning tumor may require metabolic correction. In patients with primary hyperaldosteronism, spironolactone is given preoperatively. The serum potassium levels and blood pressure should be carefully monitored. In patients with Cushing syndrome, serum glucose level needs careful monitoring and glucocorticoid replacement may be necessary. For patients with pheochromocytoma, control of blood pressure and cardiac arrhythymias is essential. This usually entails starting alpha-adrenergic blockade 2 weeks prior to surgery, with the subsequent addition of beta-blockade in the presence of arrhythmias. Some endocrinologists advocate the use of the tyrosine hydroxylase inhibitor metyrosine as preoperative medical blockade, but this regimen can be difficult to tolerate owing to side effects.

Many surgeons advocate checking a complete blood count as well. In the absence of a history of a significant bleeding or coagulopathy disorder, most patients do not require routine coagulation studies (e.g. bleeding time, PT, PTT). Any patient who is suspected of harboring a malignant mass should be evaluated for occult metastatic lesions using a chest radiograph and measurement of liver enzymes and alkaline phosphatase.

Computed tomography (CT) and magnetic resonance imaging (MRI) provide valuable information on the size of the lesion and extension of the tumor into surrounding structures, as well as characterization of the nature of the tumor. Adrenal lesions are commonly found serendipitously on imaging studies performed for other complaints, especially on CT scans. CT imaging using thin cuts, both before and after intravenous contrast, can greatly aid in the assessment of these lesions. Small lesions without enhancement after contrast and Hounsfield measurements of 15 units or less are rarely malignant and do not require further evaluation in the absence of clinical symptoms. MRI scanning can also give useful information on certain lesions such as pheochromocytoma, which has a typical bright light bulb appearance on T2-weighted images. In certain instances, ^{131}I-metaiodobenzylguanidine scintigraphy (MIBG) may be helpful, especially in localizing small or recurrent pheochromocytoma.

Preoperative preparation

A mechanical and antibiotic bowel preparation is given to all patients. This helps decompress the intestines to facilitate exposure during dissection and allows for conservative repair of any inadvertent bowel injury. A broad-spectrum antibiotic should be given perioperatively. The patients should be typed and cross-matched for 2 units of blood.

When performing a LA, general anesthesia with endotracheal intubation is used with controlled ventilation to ensure adequate oxygenation and to avoid hypercarbia. Nitrous oxide can lead to bowel distention and should be avoided during this procedure. In addition, a nasogastric tube and urinary catheter are inserted to decompress the stomach and bladder prior to creation of the pneumoperitoneum.

As always, close intraoperative monitoring of vital signs through the use of invasive lines is crucial. This includes arterial lines, central lines, and large-bore catheters for rapid fluid infusion. Anesthesiologists should also be prepared for rapid and drastic shifts in blood pressure (intraoperative hypertension and hypotension after removal of the adrenergic lesions) and should have vasoactive medications drawn and ready for immediate infusion.

Instrumentation

Standard laparoscopic equipment as described in previous chapters is used in all approaches to the adrenal gland. For dissection, employing curved dissecting scissors connected to electrocautery or a hook cautery is clearly a matter of personal choice and experience. Using high-frequency instruments (Harmonic scapel; Ethicon Endo-Surgery Inc, Cincinnati, OH, USA) or LigaSure (Valleylab, Boulder, CO, USA) to divide the adrenal vessels (except the main adrenal vein) and the surrounding fatty tissue can offer an advantage in those patients with excessive retroperitoneal fat. Small bleeders within this redundant fat can be bothersome and difficult to control during a search for the adrenal gland and its vasculature.

Intraoperative ultrasound is occasionally helpful when searching for a small lesion to enucleate. Current devices can be passed intra-abdominally, but require a larger trocar. These instruments can be difficult to use and clearly benefit from operator experience.

A retractor is also necessary to move the spleen or the liver away from the adrenal gland to allow for complete dissection. A fan device works well and should be safe on the surrounding organs if used appropriately. Malleable, shepherd's crook retractors are also available and are particularly helpful at raising the liver off Gerota's fascia and the hepatic flexure of the colon. We frequently employ a large, blunt grasper, which can be used to sweep tissues aside, as well as to grasp an edge of exposed peritoneum and thereby lift and retract the offending object or tissues.

At the end of the procedure, a specimen entrapment bag is used to retrieve the adrenal tissue. The EndoCatch device (US Surgical Corp, Norwalk, CT, USA) is easy to open and has a nice, fixed open mouth into which the specimen is delivered. The LapSac (Cook Urological, Spencer, IN, USA), however, has been proven to be impervious and is the bag of choice for any lesion that is possibly malignant. This device can be cumbersome and requires skill to keep the mouth of the bag open while passing the specimen into its interior. In all cases, open surgical instruments should be available in the operating room in the event a conversion to an open procedure is necessary.

Surgical techniques

The respective merits of a transperitoneal versus a retroperitoneal laparoscopic approach to the adrenal gland have been widely discussed in the literature. Most surgeons recognize the inherent difficulties of the reduced operating space with a retroperitoneal route, but espouse the advantages that come with avoidance of the peritoneal cavity and its risk of adhesions and trocar-site hernias. Importantly, retroperitoneal access allows for the rapid mobilization and early ligation of the adrenal vein (especially on the left side). This is particularly important for pheochromocytomas and malignant masses.

Published series have reported the need for increased surgeon experience with retroperitoneoscopy, but have not necessarily noted differences in overall complication rates [12–16]. It is important to note, however, that the retroperitoneal portions of some of these series were performed after the transperitoneal cases, making it difficult to differentiate between the importance of surgeon experience versus the importance of operative approach.

Nevertheless, there are currently no series that specifically address the benefits of one approach over the other when applied to laparoscopy of the adrenal gland. It does seem intuitive to recommend that each case should be planned on an individual basis, accounting for the size of the lesion, side of the pathology, patient's past surgical history, and experience of the surgeon.

Laparoscopic transperitoneal adrenalectomy (see Video 85.1)

The patient is placed in the lateral decubitus (45–60°) position, with the side of the lesion uppermost. This is the same position used in a flank approach for extirpative and reconstructive renal surgery. Pneumoperitoneum of 15 mmHg pressure is achieved either by open access or with a Veress needle before trocars are inserted (Figure 85.1). In general, three to four ports are used for this procedure.

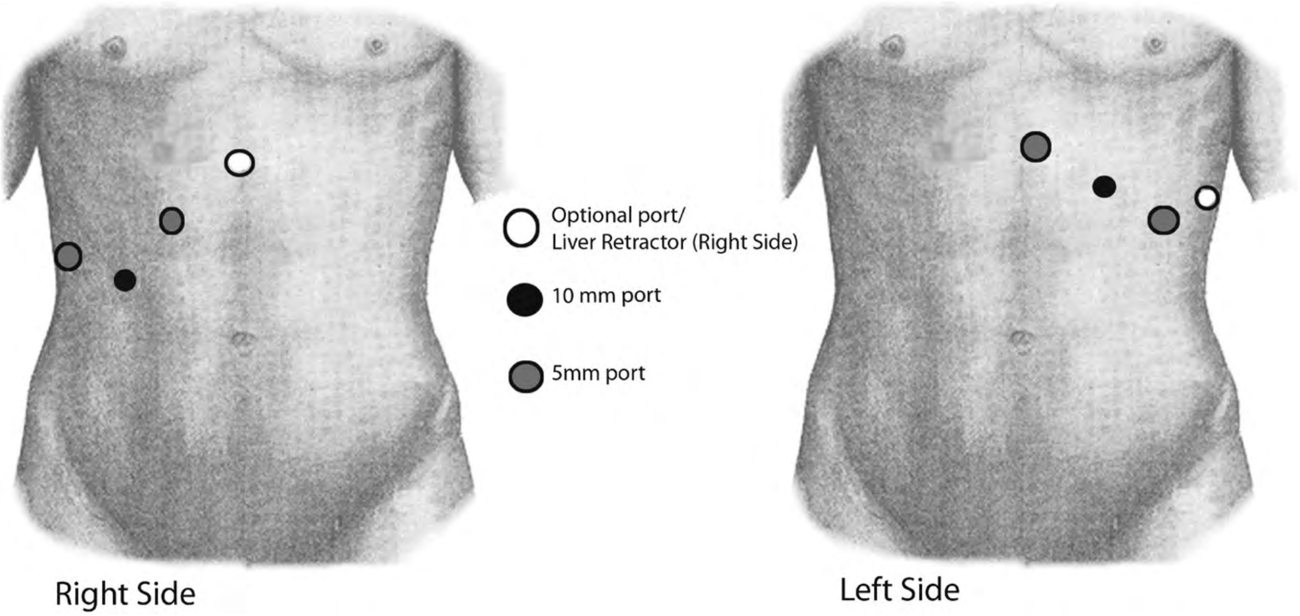

Figure 85.1 Port placement for transperitoneal laparoscopic adrenalectomy.

Right side

After adequate insufflation, the entire abdomen should be tympanic. Care must be taken during lateral insufflation to avoid intra-abdominal organ injury by the Veress needle (e.g. liver parenchyma), especially in the presence of possible adhesions. The abdominal cavity is initially inspected and any overlying adhesions are lysed. The exposure of the right adrenal gland depends on the adequate mobilization of the liver (Figure 85.2A). The triangular ligaments of the liver are incised, and the liver is gently retracted in the cephalad direction. The posterior peritoneum is incised close to the liver edge from the line of Toldt laterally to the inferior vena cava medially. The ascending colon and hepatic flexure are routinely mobilized. Gerota's fascia is then incised.

The upper pole of the kidney is identified, and the perinephric fat is dissected superiorly close to the inferior vena cava to expose the adrenal gland. The superior and anterior aspects of the adrenal gland are mobilized. Small blood vessels are controlled with electrocautery and laparoscopic clips. Dissection along the lateral border of the vena cava allows for identification of the right adrenal vein. Meticulous dissection is required to avoid tearing of the adrenal vein (Figure 85.2B). When the adrenal vein is isolated, laparoscopic clips are applied, with at least two clips on the vena cava side and one or two clips on the adrenal side. The adrenal vein is then sharply divided between the clips. The inferior and lateral aspects of the adrenal gland are mobilized. The Harmonic scalpel or LigaSure is a useful adjunct to facilitate dissection of the adrenal gland. The adrenal gland is dissected free from the surrounding structures. The specimen is placed into an organ entrapment bag before removal through one of the trocar sites (Figure 85.2C). The abdominal pressure is then lowered to 5 mmHg and the operative site is carefully inspected for bleeding before closure of the abdominal trocar sites. The 10/12-mm trocar sites require fascial closure with a 2-0 absorbable suture. A fascial closure device, such as the Puncture Closure Device (ConMed Corp, Utica, NY, USA), can be very helpful and avoids difficult and often blind suturing of the abdominal fascia. The skin is reapproximated with a subcuticular 4-0 absorbable suture. The surgical specimen is then sent to pathology for further examination (Figure 85.2D).

Left side

For a left adrenalectomy, the patient is placed in a right lateral decubitus position. Using endoscopic scissors or a Harmonic scalpel, the splenic flexure of the colon is incised along the line of Toldt. The dissection is continued superiorly to mobilize the spleen to the level of the gastric fundus. The upper pole of the kidney is exposed by freeing the posterolateral attachment of the lienorenal ligament in the direction of the diaphragm. The plane between Gerota's fascia and the pancreatic tail should be developed. The spleen is retracted superiorly and medially to expose the adrenal gland in the retroperitoneal space. This maneuver exposes the adrenal gland and will allow the dissection to begin in the correct plane. Subsequent dissection, specimen entrapment, and closure are similar to that described above for the right side.

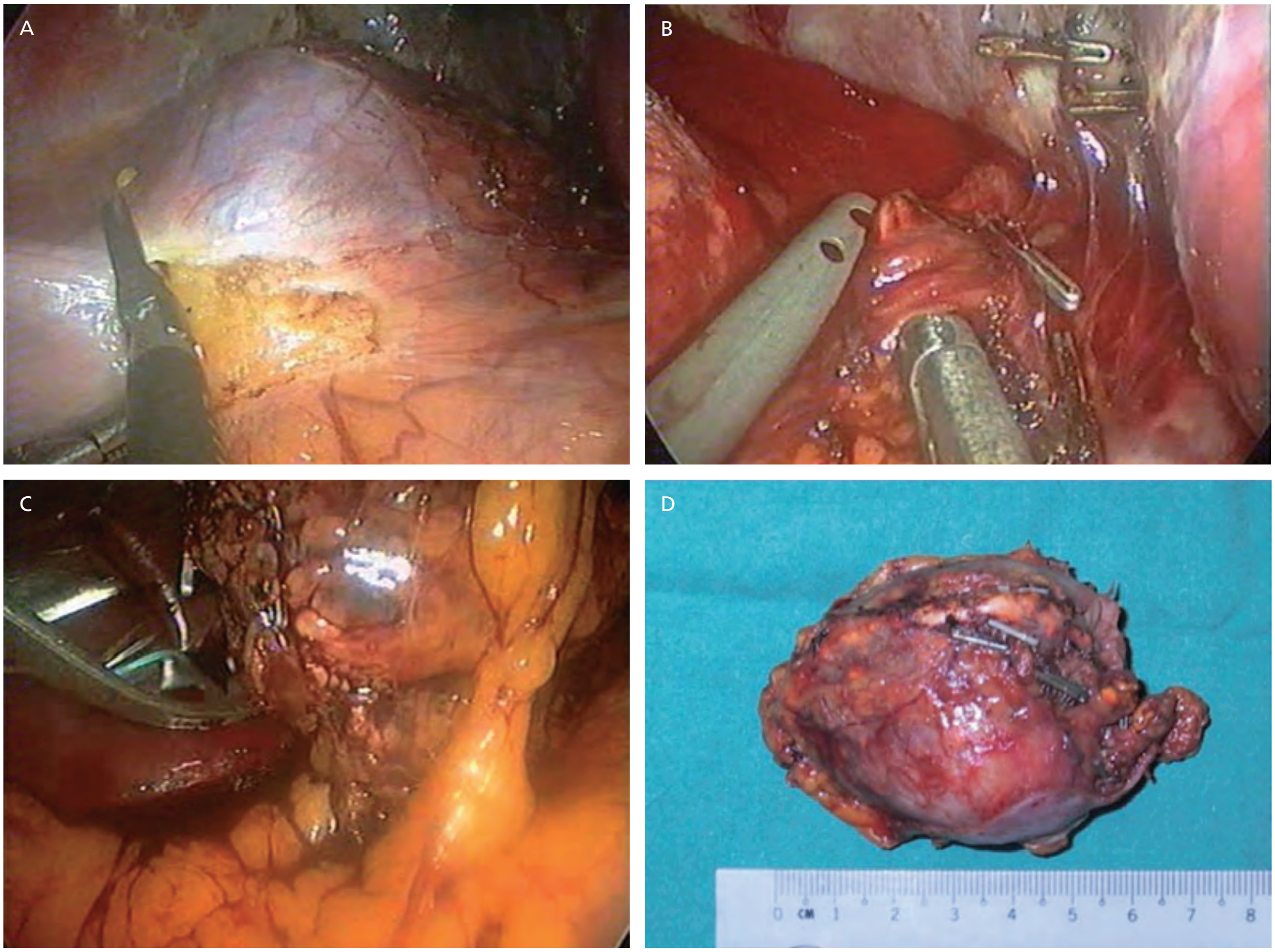

Figure 85.2 (A) Mobilization of a right adrenal tumor, (B) dissection of the right adrenal vein, (C) placement of the adrenal tumor in the entrapment sack, (D) adrenal tumor after removal; note clips on the adrenal vein.

Laparoscopic retroperitoneal adrenalectomy

Laparoscopic retroperitoneal adrenalectomy can be performed either using the lateral flank approach [13] or posterior lumbar approach [14]. The retroperitoneal LA avoids entering the peritoneal cavity and potential injury to the intra-abdominal organs. The lateral flank approach allows a more spacious working cavity, but a large tumor may obscure the surgical plane to the adrenal vessels. The posterior lumbar approach allows direct access to the main adrenal vascular supply before the gland is manipulated [15]. Depending on the surgeon's experience, a retroperitoneal approach may be used for obese patients and patients with previous abdominal surgery. However, the working space is smaller than the transperitoneal route, and this approach requires a longer learning curve.

In the more common lateral approach, the patient is placed in the full lateral decubitus position (90°) and secured in the standard fashion. The surgeon faces the back of the patient and the assistant stands on the opposite side. Initially, a small incision (2 cm) is made at the midaxillary line above the iliac crest. The incision is deepened until the retroperitoneal space is entered. The posterior pararenal space is developed using digital dissection. An adequate working space can be further developed using a commercially available balloon dilator. The pararenal space is expanded just outside Gerota's fascia. A 10/12-mm trocar is inserted and the posterior pararenal space is expanded with CO_2 gas insufflation at a pressure of 15 mmHg. The laparoscope is inserted and the other trocars are inserted under direct vision. If necessary, an additional 5-mm trocar may be placed above the iliac crest along the anterior axillary line to facilitate intraoperative retraction.

After insertion of all trocars, the insufflation pressure is then lowered and maintained at 10–12 mmHg. Gerota's fascia is incised widely in the cephalocaudad direction. Caution should be taken to avoid inadvertent opening of the peritoneal membrane. Early entry into the perirenal fat to identify the adrenal gland should be avoided, as it can produce hemorrhage, which may obscure the operative field. The perirenal fat is dissected free from the surrounding structures, which include the diaphragm (superiorly), psoas muscle (posteriorly), and medially, the pancreas (left) or liver (right). In some cases, a laparoscopic ultrasound probe may be useful in identifying the adrenal gland.

The perirenal fat is dissected to expose the plane between the adrenal gland and upper pole of the kidney. Subsequent dissection of the adrenal gland, specimen entrapment, and closure is similar to that described above for the transperitoneal approach.

Robot-assisted laparoscopic adrenalectomy

The da Vinci Robotic Surgical System (Intuitive Surgical, Sunny Valley, CA, USA) consists of a robotic manipulator with three arms (two arms for surgical instruments and one for a central camera arm) and a remote console.

The patient is placed in the lateral decubitus (45–60°) position, with the side of lesion uppermost. The abdomen is then insufflated to 12 mmHg pressure before trocars are inserted (Figure 85.3). In general, four trocars (three robotic and one accessory) are used for this procedure, with an extra accessory trocar for liver retraction in the case of right-sided lesions. Besides changing robotic instruments as necessary and manipulating the suction, the assistant is also required to use the clip applier at the accessory port for division of the adrenal vein. The subsequent operative steps for robot-assisted LA are the same as for transperitoneal LA.

Postoperative care

In the recovery room, the nasogastric tube and urinary catheter may be removed. All fluids are begun on the day of surgery, if tolerated. Besides standard postoperative care, patients should be checked for electrolyte imbalance, especially in patients with Conn and Cushing syndrome. Adrenal insufficiency may also be seen in patients with Cushing syndrome, thus requiring steroid administration. Blood pressure should also be closely monitored with appropriate antihypertensive medications administered when required. In selected patients, a postoperative endocrinologic consultation may be required. Patients are typically discharged within 1–2 days after surgery if free of complications, and may resume normal activities as tolerated.

Results

Since 1992, many studies have reported the safety and efficacy of minimally invasive techniques for adrenalectomy. The results of contemporary series are summarized in Table 85.1. Published results from peer-reviewed journals have consistently shown that LA is both safe and efficacious. Furthermore, operative times have begun to rival those of open procedures as surgeons become more experienced with this technique and with laparoscopy in general.

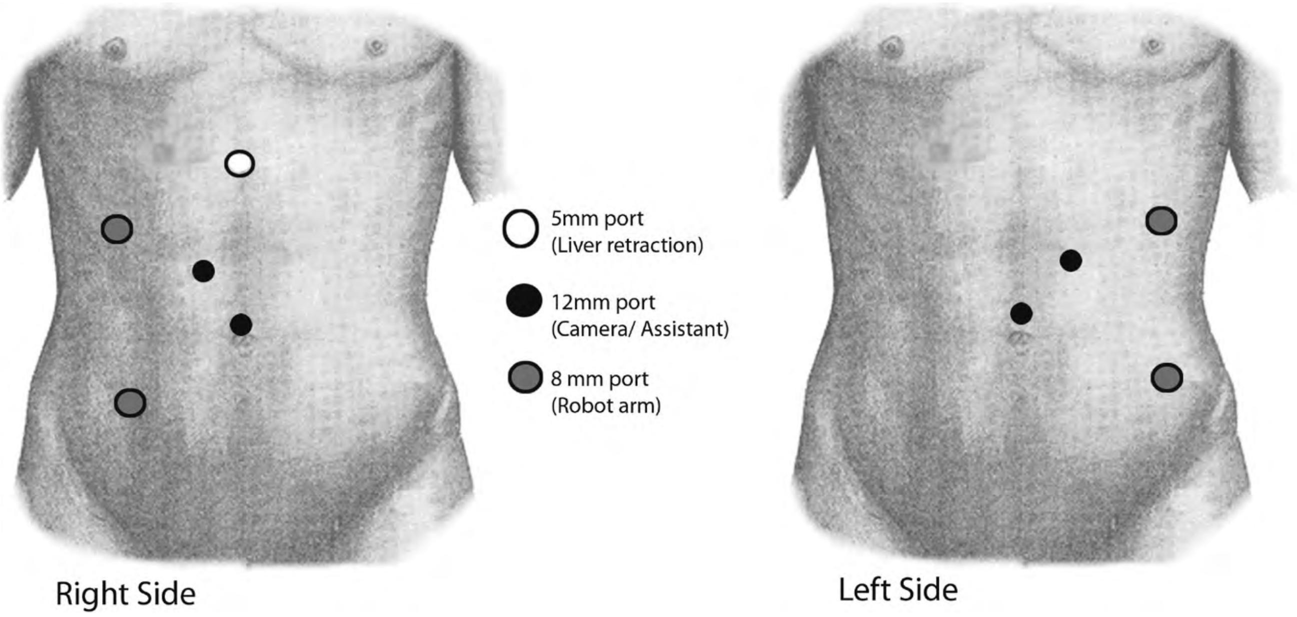

Figure 85.3 Port placement for robot-assisted laparoscopic adrenalectomy.

Table 85.1 Selected contemporary series of minimally invasive adrenalectomy.

Study	Year	Number	Approach	OT* (min)	EBL* (mL)	Hospital stay * (days)	Conversion to open surgery (%)	Intraoperative complications (%)	Postoperative complications (%)
Meria *et al.* [44]	2003	212	TP LA	102	85	3.6	14	4.7 (vascular injury, clip leakage)	10 (electrical myocardial ischemia, phlebitis, pneumonia)
Kazaryan *et al.* [45]	2009	242	TP LA	95	79	2	0	2.5 (vascular injury, minor injury to surrounding organs)	2.9 (pneumonia, hematoma)
Berber *et al.* [16]	2009	90	RP LA	138	25	1	0	0	2.2 (neuralgia)
Salomon *et al.* [46]	2001	115	RP LA	118	77	4	0.8	3.4 (vascular injury)	12.1 (hematoma, wound infection, parietal dehiscence, pneumonia)
Brunaud *et al.* [23]	2008	100	R-TP LA	99	–	6.4	5	3 (vascular injury)	3 (wound infection, pneumonia, hematoma, urinary tract infection)
Winter *et al.* [47]	2006	30	R-TP LA	185	–	2	0	0	7 (ileus, bronchitis, atelectasis)

*Reported as the mean or median according to the original paper.
OT, operative time; EBL, estimated blood loss; TP, transperitoneal, RP, retroperitoneal; LA, laparoscopic adrenalectomy; R-TP, robot-assisted transperitoneal.

At present, both surgeons and patients are eager to adopt a minimally invasive surgical approach. Recently, Park *et al*. published the outcomes of 3144 adrenalectomies [both LA and open adrenalectomy (OA)] in the USA that were performed from 1999 to 2005, a 20% stratified sample of all US nonfederal hospitals [17]. This study confirmed that LA was associated with lower complication rates, shorter hospital stay, and lower costs compared to the open approach. However, they did acknowledge that high-volume surgeons were twice as likely to perform LA, which may have a role in the 39% reduction in complication rate and a 29% reduction in hospital stay. The diffusion of robot-assisted laparoscopy may facilitate less experienced laparoscopists in adopting LA as the procedure of choice for adrenal lesions.

For functional adrenal lesions, numerous studies have reported favorable outcomes. In primary hyperaldosteronism, patients who underwent LA experienced fewer complications and a shorter hospital stay. Their blood pressure and hypokalemia were equally likely to improve [18, 19]. In patients with Cushing syndrome, the cure rate and operative and long-term morbidity were similar for the LA and OA approaches [20]. Patients with pheochromocytoma have also been successfully treated with LA [21]. Intraoperative hemodynamic values during LA for pheochromocytoma were comparable to those of traditional open surgery. Patients who underwent a laparoscopic procedure had a faster postoperative recovery [22].

Although LA has been accepted as the standard of care for benign adrenal lesions, its use in primary adrenal malignancy is still debated. Due to the rarity of primary adrenal malignancies, a randomized controlled trial comparing LA with OA is unlikely to be performed. However, several series reporting oncologic outcomes of LA and OA are available, and are summarized in Table 85.2. These data suggest that LA represents a safe and efficacious minimally invasive option in the management of noninvasive primary adrenal malignancy and should be considered as a viable option for patients with localized ACC.

Morbid obesity has been associated with increased operative times and with increased blood loss. However, Fazeli-Martin *et al.* reported that laparoscopic adrenal surgery is technically feasible in the markedly and morbidly obese patient. Compared with open surgery, it results in a quicker return of bowel function, less

Table 85.2 Selected contemporary series of open and minimally invasive adrenalectomy for primary adrenocortical carcinoma.

Study	Year	Number	Approach	Size (cm) *	Follow-up (months) *	Metastasis/recurrence	Overall survival (%)	Disease-free survival (%)
Moinzadeh *et al*. [48]	2005	6	LA	6	26	3 (42%) distant metastasis, 2 (28.5%) local recurrence	50	50
Gonzalez *et al*. [49]	2005	6	LA	5.5	28	5 (83%) distant metastasis, 3 (50%) local recurrence	20	0
Lombardi *et al*. [7]	2006	4	LA	5.9	23	0 distant metastasis, 1(25%) local recurrence	75	75
Hemal *et al*. [50]	2008	5	LA	>5	25	3 (60%) distant metastasis, 0 local recurrence	40	40
Porpiglia *et al*. [2]	2010	18	LA	9	30	4 (22%) distant metastasis, 2 (11.1%) local recurrence	94.4	66.7
Porpiglia *et al*. [2]	2010	25	OA	10.5	38	10 (40%) distant metastasis, 5 (20%) local recurrence	72	40
Terzolo *et al*. [51]	2007	130	OA	10	56.7	105 (78.9%) recurrence	50.7	19.2
Gonzalez *et al*. [49]	2005	133	OA	NR	28	56 (42%) distant metastasis, 46 (35%) local recurrence	37.6	13.5

*Reported as the mean or median according to the original paper.
LA, laparoscopic adrenalectomy; OA, open adrenalectomy.

analgesic requirements, shorter convalescence, and a reduced hospital stay [11].

A number of robot-assisted LA cases have been reported since 2001 [23–25], including a case of adrenocortical carcinoma [26] and a case of isolated adrenal metastasis treated by robot-assisted partial adrenalectomy [27]. Although robot-assisted LA has comparable perioperative outcomes with standard LA, the advantages have yet to be proven by controlled studies [28].

Complications

As with any laparoscopic surgical procedure, patient selection and the surgeon's experience are paramount. Judicious patient selection is probably the most important factor that can decrease the morbidity of a LA. Patients with relative or absolute contraindications to laparoscopic surgery should be considered for an open surgical procedure.

The size of the lesion has had a significant impact on outcomes. In general, tumors larger than 6 cm have an increased risk of malignancy. Larger lesions are also technically challenging, in part because they may distort the surrounding anatomy. This can lead to misinterpretation of the anatomic landmarks and increase the propensity towards serious, life-threatening complications. Patients undergoing adrenalectomy for large masses should also be counseled on the possibility of concurrent *en bloc* nephrectomy.

Different types of endocrinologic disorders can lead to disease-specific complications. Patients with Conn syndrome are likely to develop electrolyte abnormalities and require monitoring of blood pressure. Patients with Cushing syndrome may require postoperative steroid supplement. In patients with pheochromocytoma, close perioperative monitoring of blood pressure is essential. Cardiovascular complications, including stroke, may develop if appropriate measures are not taken.

To avoid complications, care should be taken during creation of the pneumoperitoneum. The Veress needle should be placed in proper position to avoid injury to the liver, spleen, and intestines. Alternatively, a Hasson technique for initial trocar placement can be used. During dissection, caution should be exercised to avoid injury to the surrounding structures such as the bowel and pancreas. These injuries should be recognized and repaired accordingly. When indicated, either a laparoscopic repair or open laparotomy should be performed.

Vascular complications are the most serious and may involve injury to the adrenal vessels, renal arteries and veins, and the inferior vena cava. Laparoscopic control of a vascular injury may be attempted with electrocautery or clips. In some cases, intracorporeal suturing may be used. When the patient is hemodynamically unstable or control is difficult, it is mandatory to proceed with open exploration to control the bleeding.

In the postoperative period, early ambulation is encouraged to reduce the risk of a deep vein thrombosis.

In selected patients, chest physiotherapy is required to prevent lung atelectasis. Postoperative shoulder pain is a common, though usually a self-limited, complication.

Current and future developments

Clipless and needlescopic adrenalectomy

Clipless LA obviates the use of clips during vascular control and involves the use of bipolar coagulation to control the adrenal vessels. Bipolar coagulation may be achieved using conventional electrocoagulators or modern energy-based devices, such as the LigaSure vessel-sealing system (Valleylab) or the ultrasonic coagulator (Harmonic scalpel). Misra *et al.* reported on a total of 10 patients undergoing successful uncomplicated clipless LA [29]. Bipolar coagulators can also be used for dissection, leading to less exchange of instruments. They also remove the requirement for individual dissection and isolation of blood vessels, minimizing avulsion and bleeding. However, the use of these instruments is limited by blood-vessel caliber and larger veins may not be adequately controlled by these devices alone.

Without the need for laparoscopic clipping instruments that require a 5-mm port, LA can be carried out using only needlescopic instruments. Needlescopic instruments are defined as those with a diameter of no more than 3 mm, therefore resulting in smaller incision than conventional 5–12-mm ports. Besides better cosmesis, needlescopic surgery may offer the advantage of reduced postoperative pain, hospital stay, and recovery time. Since the initial series of 15 patients by Gill *et al.* in 1998 [30], a large series of 112 patients was recently reported [31]. This series reaffirmed the safety and effectiveness of needlescopic LA for adrenal tumors less than 5 cm in size. It is important to note that needlescopic adrenalectomy should only be approached by experienced laparoscopic surgeons in carefully selected patients [32].

Laparoendoscopic single site

LESS is a novel minimal invasive surgical approach for the treatment of benign adrenal lesions. Through the development of new laparoscopic access ports (R-Port and Triport; Advanced Surgical Concepts, Ireland; Uni-X Single Port; PNavel Systems, Cleveland, OH, USA), several instruments can be inserted through multiple channels incorporated in a larger single port. Adrenalectomy is performed according to the steps of conventional transperitoneal adrenalectomy using articulated or bent instruments that permit triangulation intracorporeally despite the close proximity of several instruments (dissector, grasper, and scissors) via a single port. These instruments include roticulators (Covidien, Norwalk, CT, USA), Real Hand (Novare Surgical Systems, Cupertino, CA, USA); Autonomy Laparoangle, laparoscopic needle drivers, and endoshears (Cambridge Endo, Framingham, MA, USA).

Although a number of studies have demonstrated the feasibility and improved cosmesis of LESS [33], other potential benefits (faster recovery, earlier return to normal daily activities, etc.) are yet to be determined. A recent case–control study by Jeong *et al*. did demonstrate that LESS is a safe technique with operative time, postoperative hospital stay, and complication rate comparable to the standard laparoscopic approach [34]. Long-term follow-up is required to establish its benefits.

While LESS is a highly challenging approach in which standard laparoscopic challenges are topped by the technical difficulties of lack of triangulation and instrumentation limits, it is an appealing alternative to conventional laparoscopy. In experienced hands, LESS has been shown to be feasible given appropriate patient selection.

Partial adrenalectomy

Partial adrenalectomy (PA) represents an organ-sparing approach to the adrenal gland whereby the tumor is removed leaving as much normal adrenal tissue as possible. This approach preserves a greater hormonal reserve and may avoid the need for hormonal supplementation following adrenalectomy. Current indications include bilateral benign adrenal lesions, solitary adrenal gland, or unilateral lesions in patients with familial syndromes, such as von Hippel–Lindau, familial pheochromocytoma or multiple endocrine neoplasia type IIA [27, 35]. PA has also been advocated in Cushing adenoma and sporadic pheochromocytoma with lesions less than 30 mm in diameter, as these tumors should be considered benign and do not require radical resection [36]. The indications for PA continue to expand as the importance of organ preservation is increasingly recognized.

PA may harbor an increased risk of recurrence due to the presence of residual adrenal tissue. Although recurrences can be rectified with additional procedures, the potential disadvantages of PA should be weighed against the risk of adrenal insufficiency and therefore quality of life.

The surgical technique of PA follows the steps of conventional LA for identification and dissection of the adrenal gland and tumor. The tumor is then excised using a Harmonic scalpel or LigaSure. These instruments allow for a minimal bleeding during transection of the adrenal parenchyma. Care should be taken to preserve the vascular supply of the remaining adrenal tissue, emphasizing the importance of a careful dissection. Hemostatic agents (glues, Surgicel; Ethicon Endo-Surgery Inc) can be used for hemostasis when necessary. Employing electric current for hemostasis of the adrenal gland is not advised as it may result in hypertensive peaks intraoperatively.

Ablative techniques (radiofrequency/cryo/chemical)

Ablative techniques represent the new frontier of minimally invasive approaches and offer the benefits of low invasiveness and less technical challenges compared to conventional surgery. These advantages may translate into reduced morbidity as the procedure can be performed on an outpatient basis. Ablation techniques include radiofrequency ablation (RFA), cryoablation, and chemical ablation.

Ablation of adrenal neoplasms carries a significant risk of releasing a large amount of hormones rapidly into the bloodstream. Release of catecholamines can induce arrythmia or hypertension; thus, pretreatment with alpha- and beta-blockade is warranted.

Mayo-Smith *et al*. and Wood *et al.* have reported a series of 12 and eight patients, respectively, successfully treated with RFA for adrenal masses without major complications [37, 38]. RFA may require multiple applications, and contrast-enhanced imaging is required to ensure complete ablation of the treated adrenal lesion. The advantage of cryoablation over RFA is that the margins of cell death can be followed in realtime through visualization of the ice ball on CT. However, there have only been limited reports of adrenal cryoablation [39, 40]. Chemical ablation has seen relative success in the management of encapsulated hepatic tumors and has now been applied to adrenal neoplasm. Xiao *et al.* reported a 92.3% complete response rate for primary tumors in a large series of 36 patients [41].

The role of ablation in the treatment of adrenal tumors has yet to be determined and there have been suggestions that its greatest potential lies in the treatment of recurrent disease, small biochemically active tumors [42], as well as palliative care [43]. Ablative techniques are becoming increasingly popular in the urologic field with intensive basic and clinical research endeavors in place. Technologic advances in imaging and precise targeting of the lesions will likely enhance the appeal of these innovative approaches. However, until solid outcome data are mature, these techniques should be considered as experimental.

Conclusions

LA is safe, proven, and effective. LA currently represents the standard of care for treating patients with localized adrenal lesions. This is an advanced laparoscopic procedure and should be undertaken only by those with extensive laparoscopic experience. Technologic advances have allowed the introduction of robot-assisted LA, needlescopic, clipless, single-port LA, as well as percutaneous ablative techniques. These innovative techniques require longer follow-up and more data to assess their oncologic efficacy and perioperative outcomes. Therefore, they should be approached with caution and only be attempted if the surgeon is confident of adhering to the principles of oncologic surgery. These techniques strive towards reduced invasiveness and should not compromise the oncologic outcomes of the procedure.

We are currently witnessing a transition from conventional open to less and less invasive surgical approaches. The paradigm of open surgery for cancer is being continuously challenged and currently, with maturing laparoscopic experience, open procedures for adrenal lesions are being replaced by minimally invasive approaches with comparable efficacy.

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CHAPTER 86

Laparoscopic and Robotic Reconstructive Surgery of the Ureter

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Introduction

Conventional laparoscopic surgery is now well established for the management of a wide variety of procedures in operative urology, with well-documented advantages over open surgery [1]. Both extirpative and reconstructive procedures are performed routinely in clinical practice. A variety of ureteral pathologies, including ureteropelvic junction obstruction (UPJO), impacted ureteral calculi, ureteral strictures, and malignancies have been treated successfully with conventional laparoscopy. In this chapter we will review the laparoscopic and robotic surgical approach to pyeloplasty, ureterolithotomy/pyelolithotomy, ureterolysis, ureterovesical reimplantation, retrocaval ureter, repair of ureteral trauma, cutaneous ureterostomy, and ureterointestinal surgery.

When performing such operations, it must be kept in mind that ureteral surgery is one of the most challenging areas of urologic surgery. The small caliber and delicate nature of this organ make reconstruction particularly challenging. Intracorporeal suturing, especially in distal ureteral reconstruction in the confined working space of the pelvis when distal ureteral reconstruction, requires laparoscopic experience with free-hand suturing. As a result, reconstructive conventional laparoscopic procedures have not been widely adopted by community urologists, and are performed only in centers where advanced reconstructive procedures are carried out regularly with success equivalent to that of open surgery.

Robotics solves many of the technical complexities that are prohibitive in laparoscopic surgery, most notably precise cutting, intracorporeal suturing, and knot tying for reconstruction. Thus, robotic surgery may shorten the learning curve for laparoscopic reconstructive procedures for surgeons with no or minimal laparoscopic training [2, 3], making reconstructive ureteral laparoscopic surgery more widely available in centers with less laparoscopic experience. Despite cost acquisition issues, the da Vinci robotic system (Intuitive Surgical Inc, Sunnyvale, CA, USA) is being used by more and more urologists. As a result, the same variety of ureteral pathologies treated by conventional laparoscopy is now being treated by robot-assisted laparoscopy with equivalent success.

Good knowledge of ureteral anatomy, and proper patient selection and preoperative evaluation are similarly necessary for both conventional and robotic reconstructive laparoscopy.

Anatomic considerations

A comprehensive knowledge of ureteral anatomy is essential when performing either a pure or a robot-assisted laparoscopic procedure.

For surgical purposes, the ureter is divided into the abdominal or upper portion, and the pelvic or lower portion. The abdominal ureter extends from the kidney to the iliac vessels. It originates at the UPJ and courses along the psoas muscle before crossing the genitofemoral nerve at the level of the fourth lumbar vertebra. The gonadal vessels pass anteriorly over the mid upper ureter. The ureter extends toward the pelvic brim to cross the external iliac vessels on the right and the

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common iliac vessels on the left. Once the ureter has entered the pelvis, it courses posterior and medial to the medial umbilical ligament and enters the detrusor muscle just posterior to the superior vesical artery. Important structures adjacent to the distal ureter include the vas deferens in the male, and the round ligament, uterine artery, and broad ligament in the female. These structures lie anteriorly and need to be divided to gain access to the distal ureter.

The upper ureter derives its blood supply from the renal artery, the mid ureter is fed by branches from the aorta and gonadal artery, while the lowermost portion of the ureter is served by branches of the common iliac, internal iliac, and vesical arteries. Once these vessels reach the ureter they course longitudinally within the periureteral adventitia, forming an extensive plexus. As such, ligation of much of the blood supply will not impact on viability in a healthy ureter.

It is important to recognize the normal relationship between the renal pelvis and the hilar vessels. The renal artery and vein are anterior to the renal pelvis, with the vein located most anterior. The renal artery divides into several branches, with the posterior being the most consistent and first to branch. The anterior branch divides into four segmental arteries (apical, upper, middle, and lower). Anomalous blood vessels can supply segments of the kidney. Lower pole vessels causing UPJO usually course anterior to the ureter.

Gerota's fascia is connected to the lateral parietal peritoneum by the lateroconal fascia. The space between this fascia and the posterior peritoneum is the anterior pararenal space, whereas the space dorsolateral to this fascia is the posterior pararenal space. This is the space entered during retroperitoneoscopy.

Of importance is the way the posterior peritoneum and the lateral peritoneal reflexion behave when the patient changes position. Moving the patient from a supine to a flank position displaces the peritoneal reflexion from the posterior axillary line anteriorly because of the downward movement of the colon. This increases the retroperitoneal space and decreases the potential of entering the peritoneal cavity when placing the trocars for retroperitoneoscopy.

The pelvic extraperitoneal space where the lower ureter will be found is the preperitoneal space caudal to the pelvic brim and between the parietal peritoneum and the fascia transversalis. Retzius' space is also considered a part of this space.

Patient selection

Patients with uncorrectable bleeding abnormalities, abdominal wall infection, generalized peritonitis; malignant ascites, and massive hemoperitoneum are at higher risk during laparoscopic surgery, pure or robot assisted. Large aortic and iliac aneurysms, and history of previous renal trauma or prior retroperitoneal or transperitoneal surgery can increase the difficulty of the procedure, but do not preclude laparoscopy, conventional or robot assisted, from being performed by a surgeon with laparoscopic expertise. Informed consent should always be obtained not only for the laparoscopic or the robotic procedure, but for an open procedure as well, in case conversion becomes necessary. The patient should know the procedure-dependent complications, as well as the complications involved with pure or robot-assisted laparoscopy itself.

Preoperative evaluation and preparation

A complete history and physical exam should always be recorded. Laboratory testing should be individualized, but urine should always be collected for microscopic analysis and/or culture. A blood type and screen should be available for all patients. No Aspirin or Aspirin-like compounds should have been taken within 5–7 days of surgery.

Radiographic and other specialized preoperative studies will be discussed for each surgical technique. X-ray films should be available and placed on the view box of the operating theater before the operation begins.

Pyelography should be the starting point in the evaluation of a patient with ureteral pathology. The intravenous or computed tomography (CT) pyelograms define the anatomy of the collecting system on the affected side. A diuretic nuclear renal scan is helpful in quantifying the degree of obstruction, if present, and documents the relative percentage of kidney function. The function of kidneys with high-grade obstruction is best assessed after the kidney is drained. A retrograde pyelogram is helpful in evaluating the ureter and delineating the length of obstruction if not seen on other imaging.

Operative preparation

Many of the preoperative steps are common for all conventional and robotic laparoscopic ureteral reconstructive procedures. Attention to these details will facilitate successful visualization of the ureter and minimize complications. A combination of ampicillin and gentamicin or a single dose of a third-generation cephalosporin is administered intravenously on arrival at the operating room. Pneumatic compression stockings are placed before induction of general anesthesia. A nasogastric or orogastric tube should be placed and the stomach emptied. The bladder should also be emptied using a Foley catheter. Placement of a ureteral stent before or during the laparoscopic procedure is at the surgeon's discretion.

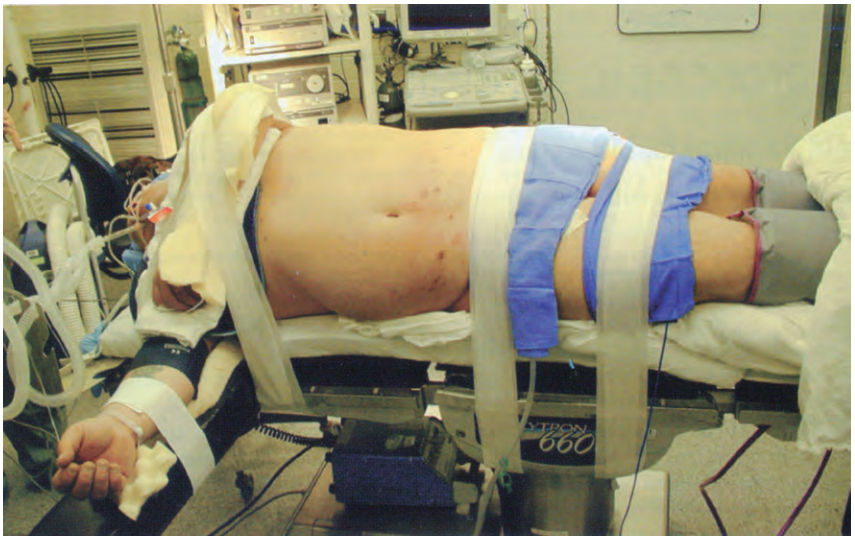

Figure 86.1 Modified lateral position of a patient undergoing conventional or robot-assisted laparoscopic reconstructive surgery of the upper ureter.

Positioning of the patient depends on the part of the ureter to be reconstructed, and is similar for both conventional and robot-assisted laparoscopy. For upper ureteral laparoscopic procedures, the patient is placed in a lateral or semi-lateral decubitus position. Some surgeons prefer the complete flank position or the 100° lateral semi-prone position, especially if the retroperitoneal approach is selected. This provides more space for trocar and instrumentation placement. Additional space can be obtained by breaking the operating table at the kidney level. A roll is placed behind the back to support the patient and the contralateral arm is padded and tucked alongside the patient (Figure 86.1). The ipsilateral arm is draped across the chest over egg-crate padding with the elbow gently bent cephalad. The ipsilateral shoulder is also rotated cephalad to move the arm away from the operative field, allowing maximal mobility of the laparoscopic instruments as well as of the robotic arms. The hips and legs are kept supine, with a pillow placed behind the knees and padding at the heels. Wide cloth tape is placed across the shoulder and hip to secure the patient to the table. The lower legs should be secured with tape or straps below the knees. The table should be test rolled prior to placing the drapes to be certain that the patient is secured to the operating table. The abdomen and exposed flank are shaved and prepared from the xiphoid to mid thigh, including the genitals in some cases.

Monitors for conventional laparoscopy are positioned at the upper third of the table across from the surgeon and assistant (Figure 86.2). During transperitoneal surgery, the surgeon is positioned on the abdominal side of the patient. During the retroperitoneal approach, the surgeon is positioned on the flank side of the patient.

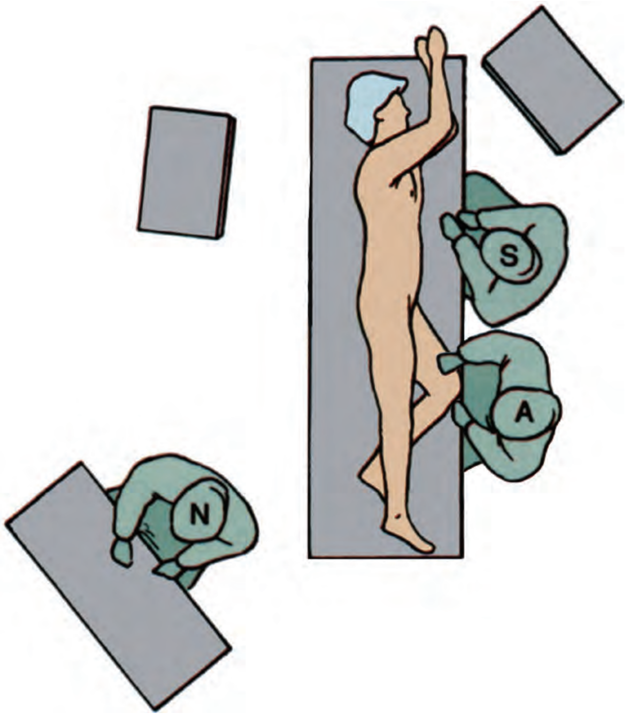

Figure 86.2 Positioning of operating room equipment and personnel for laparoscopic approach to right abdominal ureter. S, surgeon; A, assistant; N, nurse.

During transperitoneal robot-assisted laparoscopy for reconstruction of the upper ureter, the robot is placed on the ipsilateral side of the kidney being operated on (Figure 86.3). The assistant is situated on the other side. Although rarely used when the retroperitoneal approach is selected, the robot is docked from the abdominal side.

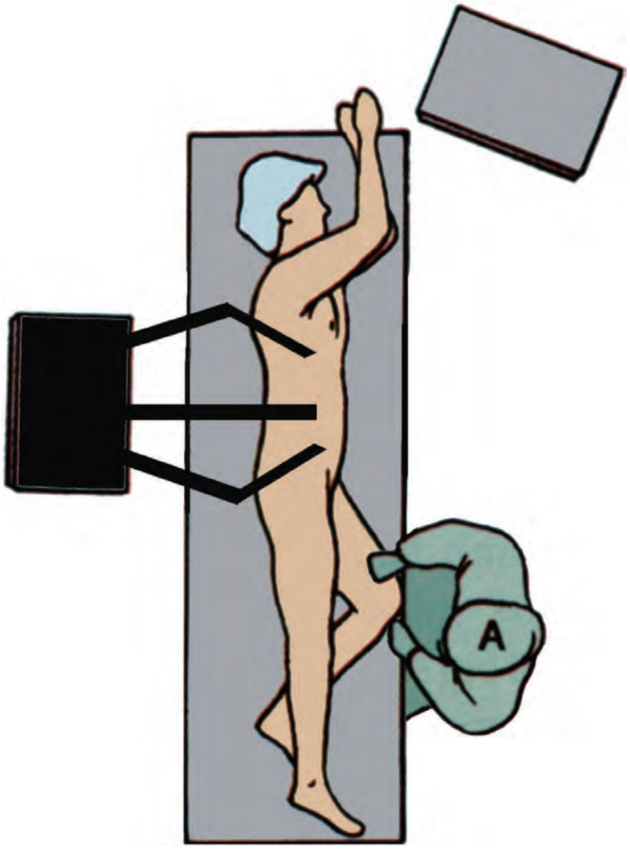

Figure 86.3 Positioning of robotic arms for robot-assisted laparoscopic approach to right abdominal ureter. A, assistant.

For conventional and robot-assisted lower ureteral laparoscopic reconstructive procedures, the patient is placed in the supine position. Each arm is positioned alongside the patient. Additional padding is placed along the arms, and under the knees and heels. For robot-assisted lower ureteral surgery, the patient's legs are placed in a low modified lithotomy position, comfortably supported using Allen stirrups (Allen Medical Systems, Acton, MA, USA). The patient is secured on the table with tape and special belts in case lateral flexion is needed. The monitors and robotic system are placed at the feet of the patient (Figure 86.4).

Access

Transperitoneal access

Port placement during conventional laparoscopy is individualized for each procedure. The trocar size chosen varies with each case and according to surgeon preference. During robot-assisted laparoscopy, trocar configuration may be very similar to that used for conventional laparoscopy; however, it must be kept in mind that two to three 8-mm nondisposable ports specifically designed for the da Vinci system are used, and should be placed at least a hand's length apart or a minimum of 9 cm away from each other to avoid collision problems with the working arms of the robot.

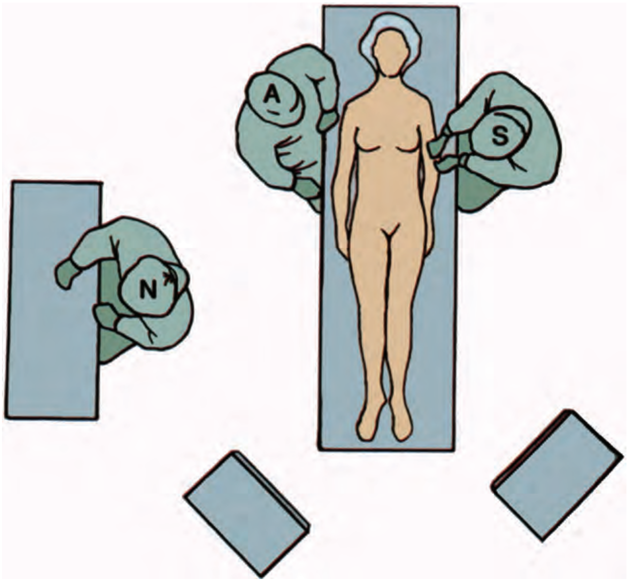

Figure 86.4 Positioning of operating room equipment and personnel for laparoscopic approach to right pelvic ureter. S, surgeon; A, assistant; N, nurse.

The upper ureter can most easily be accessed with the patient in the flank position. To establish a pneumoperitoneum, a Veress needle is introduced into the umbilicus. The peritoneal cavity is insufflated to a pressure of 15–20 mmHg. Usually three midline trocars are used for upper ureteral conventional laparoscopy: a 10-mm umbilical trocar, a 5-mm trocar one-third inferior to the xiphoid, and a 12-mm trocar half way between the umbilicus and pubis (Figure 86.5). Instead of the midline configuration, a trigonal or rhomboidal arrangement can be used (Figure 86.6). An additional fourth trocar may be used for assistance according to the surgeon's requirements. Trocars for robot-assisted laparoscopy are placed in V-shape fashion using two 8-mm trocars, one placed lateral to the rectus muscle at a level higher than the umbilicus and the other around 3 cm above and medial to the anterior superior iliac spine at a level lower than the umbilicus. A third 10–12-mm disposable umbilical trocar is used to accommodate the camera. An additional 10–12-mm midline port can be placed below the umbilicus in order to permit suction or quick suture exchange with the help of the assistant (Figure 86.7).

Trocar placement to approach the lower pelvic ureter is accomplished with the patient in a supine position and is the same for conventional and robot-assisted laparoscopy. A Veress needle is placed through the umbilicus, and pneumoperitoneum is established to a

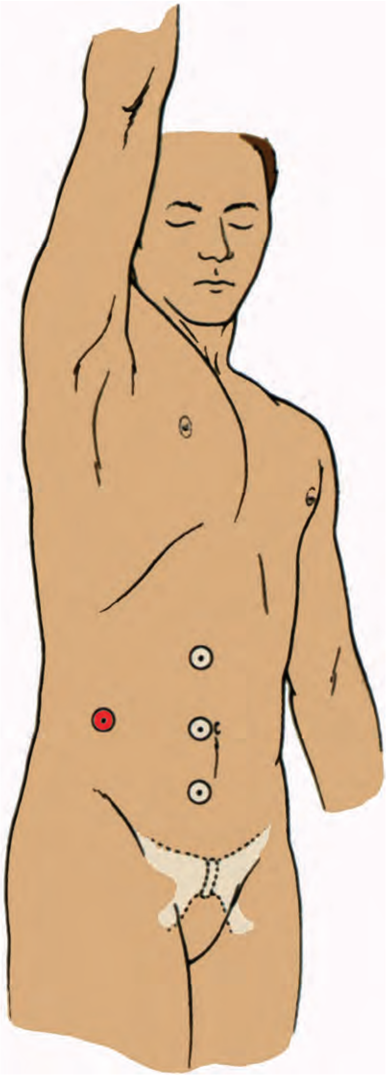

Figure 86.5 Linear port placement for conventional laparoscopic approach to abdominal ureter. The optional 5-10-mm port (red) is used for retraction.

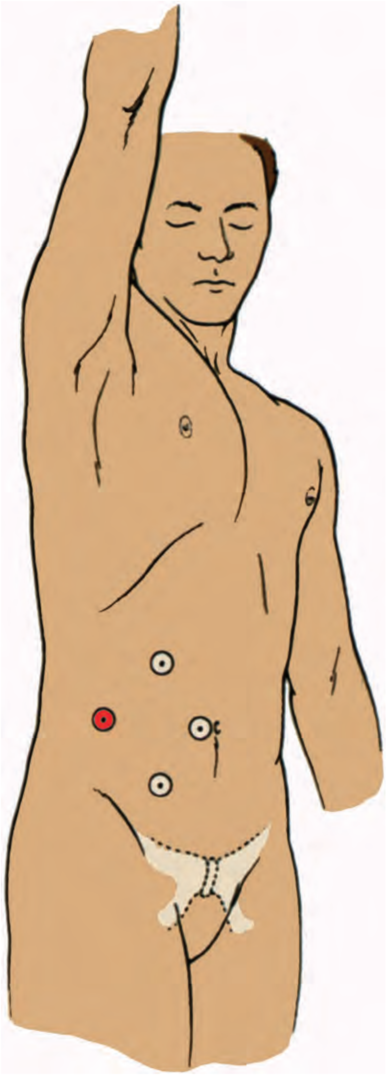

Figure 86.6 Trigonal port placement for conventional laparoscopic approach to abdominal ureter. The optional 5-10-mm port (red) is used for retraction (diamond-shaped configuration).

pressure of 15–20 mmHg. Initial trocar placement is performed through a semicircular 1-cm incision at the umbilicus, through which the camera will be inserted. One or two ports are positioned in each lower quadrant 2 cm medial to the corresponding anterior superior iliac spine (Figure 86.8). Again, during robot-assisted procedures two similarly placed 8-mm trocars, specific for the robot, are used. An additional 10–12-mm trocar can be placed suprapubically in order to permit suction or quick suture exchange with the help of the assistant. The configuration provides optimal access to the pelvic ureter from the iliac vessels to the ureterovesical junction (UVJ). In addition, if conversion is necessary, a shallow Pfannensteil incision can be made to include all three port sites. When approaching the entire ureter, a combination port placement is required (Figure 86.9).

All ports are secured in position with 2.0 Vicryl sutures. In case of scars due to prior surgery, either the Hasson cannula is preferred or the Veress needle is initially placed in a scar-free area of the abdomen, preferably the upper left or right quadrant.

Retroperitoneal access

With the patient in a flank position, the table is flexed, opening the costoiliac space. A 2-cm skin incision is made below the tip of the 12th rib. The flank muscle fibers are bluntly separated using the S-retractors. After the anterior thoracolumbar fascia is opened and access to the retroperitoneum is gained, finger dissection between the psoas muscle and the posterior side of Gerota's fascia is performed in order to create the initial

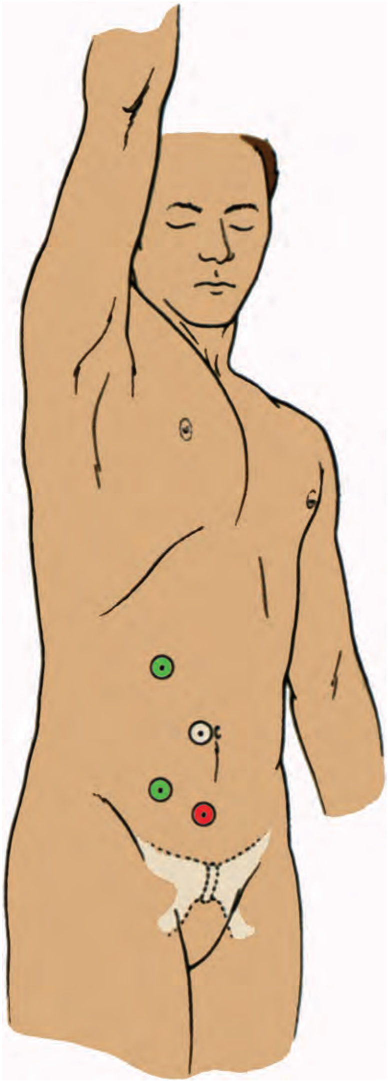

Figure 86.7 Port placement during robot-assisted laparoscopic approach to abdominal ureter. The green colored trocars represent specific robotic 8-mm trocars. The optional 5-10-mm port (red) is used by the assistant for retraction, suction or fast suture exchange. It is placed below the umbilical trocar or on the contralateral lower quadrant, depending on surgeon's preference.

space where the balloon dilator will be placed. Mobilization can be carried anteromedially in order to bluntly detach the lateral peritoneal deflection from the undersurface of the anterolateral abdominal wall to allow more space for the trocar placement. A trocar-mounted silicone balloon distention device [4] (Origin Medsystems, Menlo Park, CA, USA) is placed in the space made in the retroperitoneum. Installation of 800 mL of air in the balloon will create adequate space; 400 mL is sufficient in the pediatric population. For ureteral surgery, secondary balloon dilation caudal to the initial site of dilatation can be performed in order to have access to the middle and lower ureter.

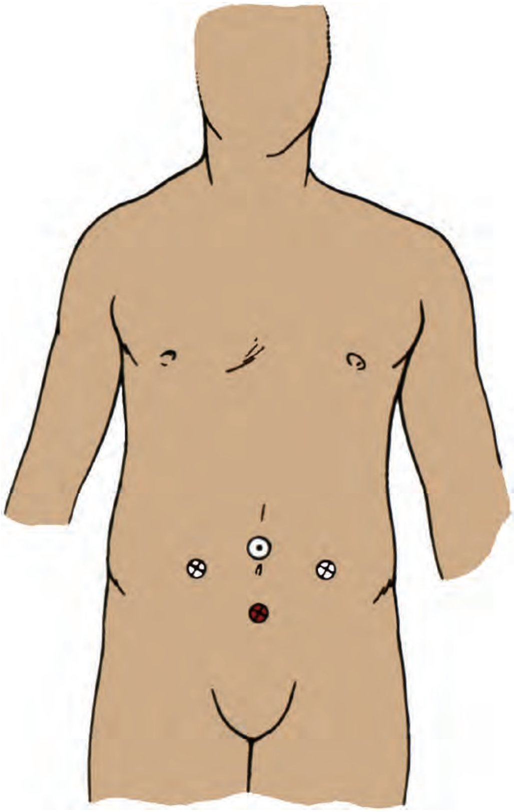

Figure 86.8 Port placement for conventional laparoscopic approach to the pelvic ureter.

Following balloon deflation and removal of the device, a 10-mm Bluntport trocar (Origin Medsystems, Menlo Park, CA, USA) is placed in the 2-cm incision. This trocar has an internal fascial retention balloon and an external foam cuff, which provides a better airtight seal. Pneumoperitoneum is achieved and the remaining ports are placed with a combination of direct camera guidance and manual control. Attention is needed not to enter the peritoneal space. The limited retroperitoneal space forces the trocars to be placed closer to one to another. This theoretically could be a problem for the robot-assisted approach since the robotic arms may collide.

Although individualized, the camera is placed through the 10-mm primary port, while a set of secondary ports are placed, one at the anterior axillary line, two to three finger breadths above the anterosuperior iliac spine, and the other at the lateral border of the paraspinal muscles along the inferior border of the 12th rib. A fourth auxiliary port can be placed along the anterior axillary line at the level of the costal border above the camera port (Figure 86.10). Robot-assisted laparoscopy is rarely used for ureteral reconstructive surgery and reports concern mostly the pediatric population [5]. The two 8-mm reusable ports are placed as described above for the conventional retroperitoneal approach.

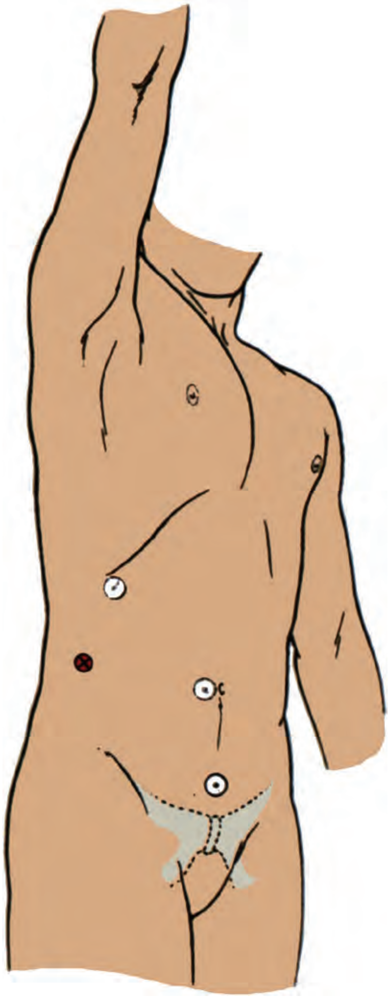

Figure 86.9 Combination port placement for access to the entire ureter.

Ureteropelvic junction obstruction

UPJO can be caused by a congenital intrinsic narrowing of the lumen or by external compression, usually by a crossing vessel. Preoperative evaluation includes a diuretic renogram and an intravenous pyelogram (IVP). Confirmation can be obtained at the time of surgery with a retrograde pyelography. Other diagnostic methods, such as CT angiography [6], endoluminal ultrasonography [7], and contrast-enhanced Doppler ultrasonography [8], can be used in case an obstructing vessel is suspected [9]. When laparoscopic repair is scheduled, the above-mentioned tests are not mandatory. Direct intraoperative observation obtained at laparoscopy will diagnose a crossing vessel.

Open pyeloplasty for the repair of UPJO was the standard treatment for several decades, with success rates of greater than 90% reported in several large series [10, 11]. The morbidity associated with a flank incision, however, has led to the development of minimally invasive retrograde and antegrade approaches to UPJ repair. Despite short hospital stay and rapid recovery, these endoscopic techniques have lower success rates, ranging from 65% to 87% [12, 13]. Success is even lower in the presence of a crossing vessel or a very dilated pelvis and poor renal function [14–16].

In 1993, laparoscopic pyeloplasty was introduced to reconstruct the UPJ under direct vision. The rational was to develop a procedure that had the advantages of minimal morbidity achieved with endourologic approaches while maintaining the high success rates of open pyeloplasty. This approach has been successful in a variety of pathologies, including patients with UPJO secondary to a crossing vessel, high ureteral insertion, large redundant renal pelvis, or those who failed a prior endoscopic repair.

Despite the presence of a large number of series of conventionally performed laparoscopic pyeloplasties,

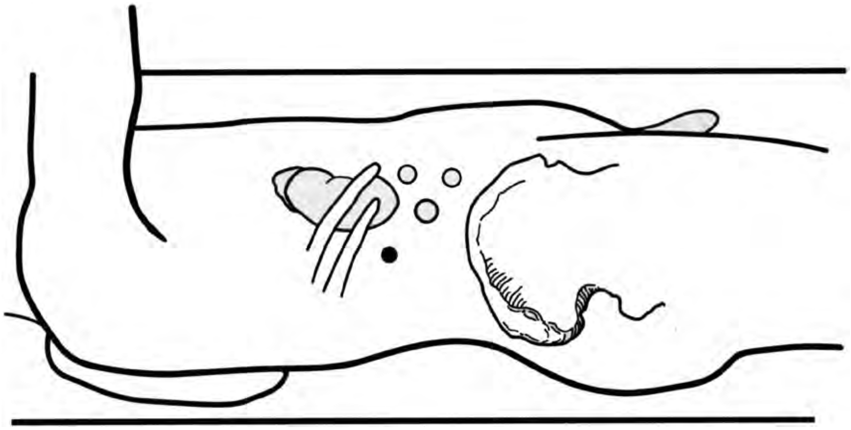

Figure 86.10 Port placement during retroperitoneal access to the abdominal ureter.

this procedure requires experience with laparoscopic free-hand suturing, which is quite a challenging task for a urologist located outside a high-volume laparoscopic center. The introduction of robot-assisted laparoscopy has made the task of laparoscopic suturing required for pyeloplasty easier to master. Therefore, robotic pyeloplasty is rapidly evolving as an equivalent therapeutic option for UPJO management.

Technique

Transperitoneal approach

The patient is positioned in a lateral position for access to the upper ureter (see Figure 86.1)., A retrograde pyelogram is obtained and, depending on surgeon preference, a 7F double pigtail ureteral stent is placed beforehand, or the stent is placed in an antegrade fashion during the laparoscopic procedure, using one of the laparoscopic ports or a 16G angiocatheter. It is important to select a stent that can extend from the bladder to the upper pole collecting system to prevent the curl of the stent from lying at the anastomosis, because this will make reconstruction more challenging. Port placement for access to the UPJ may be augmented by an additional 5-mm trocar placed in the anterior axillary line midway between the costal margin and the iliac crest (see Figures 86.5 and 86.6). Similarly, an additional port may be placed during robotic pyeloplasty at a similar location to that for conventional laparoscopy, to form a rhomboid configuration. Many robotic surgeons prefer to place the assistant's trocar at the midline or the contralateral side at a level midway between the umbilicus and pubis (Figure 86.7). All types of pyeloplasty can be performed with success both with conventional and robot-assisted laparoscopy. The most commonly performed type of laparoscopic pyeloplasty is the dismembered one (Anderson Hynes).

The surgical steps of a dismembered pyeloplasty are identical for conventional and robotic laparoscopy. The kidney and renal pelvis are identified lateral to the colon just beneath the peritoneum. The peritoneum overlying the kidney is incised from the upper pole to 4cm below the lower pole, and the colon is retracted medially. Positioning the patient laterally allows the colon to fall medially. The ureter can usually be identified by following the psoas muscle medially from the lower pole of the kidney (Figure 86.11). A sweeping motion with graspers perpendicular to the course of the ureter is used to bluntly dissect loose areolar tissue and identify the ureter. Dissection around the ureter distal to the UPJ should be minimized to preserve blood supply. In conventional laparoscopy, palpation of the indwelling ureteral stent aids in following the course of the ureter to the UPJ. During robot-assisted laparoscopy, palpation of the stent is not possible and its identification relies on optical cues. Care should be taken not to confuse the gonadal vessels and the ureter. If these vessels are impeding adequate visualization, they can usually be swept medially, but on occasion they need to be ligated and transected. Once the renal pelvis is identified, it should be dissected free to obtain adequate length to perform a tension-free repair. If a lower pole crossing artery is encountered, preservation is recommended to maximize future renal function. Alternatively, in patients with a thin mesentery, access to the UPJ can be obtained without reflecting the colon, but with a transmesocolic approach.

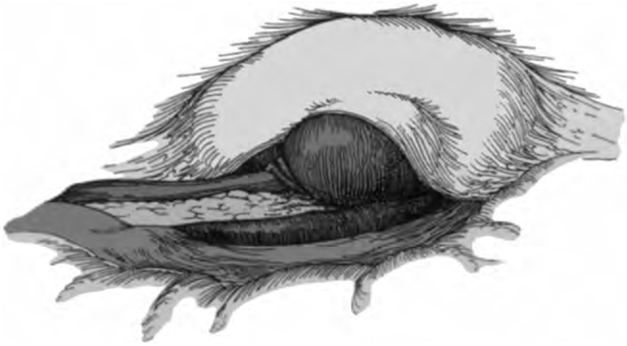

Figure 86.11 Incision of the peritoneal reflexion and medial mobilization to the colon to expose the right ureteropelvic junction.

Once the UPJ is developed, scissors are used to transect the renal pelvis above the UPJ, and care should be taken not to spiral the incision or cut the ureteral stent if present. During robot-assisted pyeloplasty, several surgeons prefer to dock the robot at this point in order to use the robotic Potts scissors and continue the procedure robotically. Other surgeons prefer to dock the robot from the start and perform the entire procedure robotically, including identification and dissection of the UPJ. The proximal end of the stent is pulled from the pelvis after the anterior incision in the renal pelvis is completed. Spatulation of the ureter can be performed before or after the posterior wall of the pelvis is incised and the diseased portion of the UPJ removed. Care must be taken not to pull the stent out of the ureter during this maneuver. A reduction pyeloplasty can be performed at this time if necessary.

If an anterior lower pole vessel is encountered, it is transposed behind the renal pelvis. A 4-0 Vicryl suture is placed between the apex of the spatulated ureter and the dependent portion of the renal pelvis. The posterior row of sutures is then placed using interrupted or running 4-0 Vicryl sutures. If the stent is not present, it can be placed at this moment. Clamping the Foley catheter 1h earlier to distend the bladder may allow the ureteral stent to pass more easily into the bladder during antegrade placement. In addition, indigo carmine is instilled into the Foley catheter to observe for backflow into the proximal ureter and confirm proper distal placement of the double-J stent if this in doubt. The proximal end of the ureteral stent is then repositioned in the renal pelvis, and the anterior row of interrupted or running sutures is placed. The excess pyelotomy incision above the repair is closed using a running 4-0 Vicryl suture (Figure 86.12). During robot-assisted pyeloplasty, haptic feedback is not present and care must be taken to avoid crush injury of the ureter from the robotic graspers and knot tearing due to secondary excessive force. However, suturing in particular is easier due to the infinite angulations the needle holders can make.

A 5-mm suction drain is placed through the lateral 5–10-mm port site. This drain is positioned near the posterior aspect of the reconstructed UPJ and secured externally to the skin with a 3-0 silk suture. The colon is replaced in its original position over the repair, and the procedure is concluded in a standard fashion.

The nasogastric tube is removed in the operating room, and the Foley catheter is taken out on the second postoperative day. The flank drain is removed when drainage becomes negligible, usually by the second postoperative day. If drain output increases, the Foley catheter is placed again for 48 h. A clear liquid diet is begun on the night of surgery and advanced as tolerated. Parenteral antibiotics are continued for 24 h. The ureteral stent is removed 3 weeks postoperatively. The repair is evaluated on an IVP 6 weeks after stent removal, and a nuclear renal scan is obtained at 3 months postoperatively.

Retroperitoneal approach

The patient is placed in a flank extended position. After developing the retroperitoneal space off the tip of the 12th rib and pneumoretroperitoneum established, two secondary ports are placed as described for access to the upper ureter (see Figure 86.10). An additional assistant trocar is optional, but usually necessary for robot-assisted pyeloplasty.

The retroperitoneal approach, although offering less space than the transperitoneal approach, has the theoretical advantage of identification of the ureter immediately after entering the retroperitoneal space. If the ureter is not readily seen, attention is paid to the hilar fat in order to identify the pulsating renal artery, and this will lead to the renal pelvis. Orientation in the retroperitoneal space can be difficult and this difficulty is enhanced when the computer-assisted system is used, since the surgeon is positioned remotely from the patient and has little sense of up and down. However, with experience, leaving the console to check instrument position will only rarely be needed.

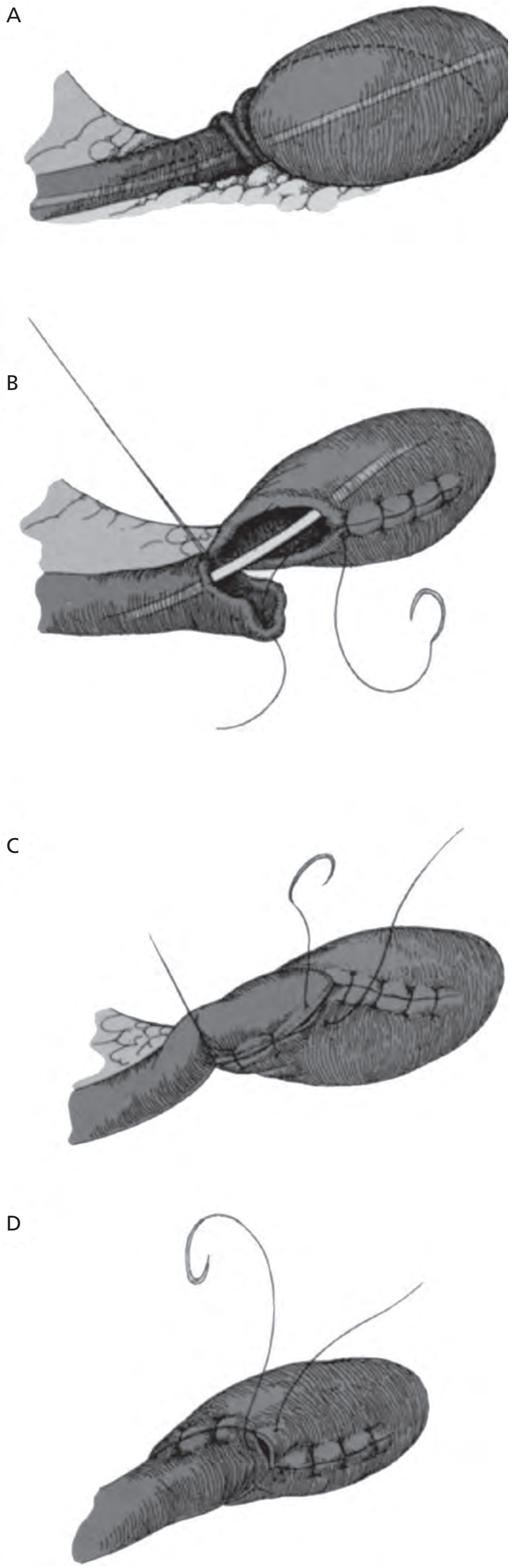

Figure 86.12 Reconstruction of a ureteropelvic junction by a lower pole crossing vessel. (A) Proposed incision. (B) Apex of spatulated ureter is anastomosed to the dependent portion of the renal pelvis after lower pole vessel posterior transposition. (C) Rotation of the ureter to provide access for posterior rows of interrupted sutures. (D) Completion of the anterior row of sutures to complete anastomosis.

Table 86.1 Results from series of conventional laparoscopic pyeloplasty.

Study	Number of patients	Access	Mean operative time (min)	Mean blood loss (mL)	Mean hospital stay (days)	Complication rate (%)	Success rate (%)	Mean follow-up (months)
Inagaki *et al.* (2005) [17]	147	Trans	246	158	3.1	8.8	95	24
Jarrett *et al.* (2002) [18]	100	Trans	252	181	3.3		94	29
Mayens *et al.* (2008)[19]	92	Trans	250	63	1.2	3.2	92	13
Janetschek *et al.* (2000) [39]	65	Retro	123	0	4.1	3	98	25
Zhang *et al.* (2006) [20]	56	Retro	80	10	7	3.6	98.2	30.2
Soulie *et al.* (2001) [21]	55	Retro	185	59.6	4.5	12.7	88	14.4
Eden *et al.* (2001) [22]	50	Retro	165		2.6	4	81.2	18.8
Turk *et al.* (2002) [23]	49	Trans	165	0		0	97.7	23.2
Klingler *et al.* (2003) [24]	40	Trans /retro			5.9	17.5	87.5	19.4

Further ureteral dissection and pyeloplasty technique are performed as described previously for the transabdominal approach.

Results

Several large series of laparoscopic pyeloplasties demonstrate success rates equivalent to open surgery (Table 86.1) [17–24]. The benefits of avoiding the morbidity of a flank incision are clear. Compared to the open approach, the laparoscopic approach unequivocally offers a decreased need for analgesics, shorter hospital stay, and faster recovery. Complication rates are similar, if not lower, for the laparoscopic approach in several series. Most complications relate to the initial misplacement of the double-J stent or conservative treatment of anastomotic leakage. The procedure is almost never converted to open surgery and is performed with minimal blood loss in most cases. However, operative times are longer than those required for open surgery. This is attributed to the fact that laparoscopic suturing is challenging and requires experience to become time efficient, and the time taken for retrograde stenting must also be taken into consideration. With experience, overall operative times decrease.

Several large series of robot-assisted pyeloplasties have been reported (Table 86.2) [25–31]. Success rates are greater than 90% and comparable to those obtained with open surgery. Again compared to open pyeloplasty, analgesic requirements are less, hospital stay is shorter, and recovery is faster. Complications are similar. Average operative time is variable among studies, and robotic set-up time, technique used, and resident mentoring time may play a role. Several studies have compared the conventional to the robot-assisted approach (Table 86.3) [32–37]. Blood loss, analgesic requirements, complications, and success rates were similar between the two laparoscopic modalities. What is controversial is which modality is faster and has a shorter hospital stay. In the series by Link *et al.*, operating time for conventional pyeloplasties was shorter compared to that for robotic pyeloplasties; under the condition, however, that all procedures were performed by an experienced laparoscopic surgeon [33]. Contrary results were reported from the series in Innsbruck, where robotic pyeloplasty was faster than conventional pyeloplasty [34]. A meta-analysis of all reported comparative studies showed that robot-assisted pyeloplasty reduced operative time by 10 min only ($P = .15$), but was significantly associated with a shorter hospital time ($P < .01$) [38]. Data from this meta-analysis need further evaluation since the contributing studies included small numbers of patients, surgeons of varying experience, variable techniques, and no controls. Most authors consider that suturing during robot-assisted pyeloplasty is easier and faster. Obviously, this is less evident for a surgeon with large experience with laparoscopic suturing, but for the less experienced urologist the robot may facilitate the learning process.

Table 86.2 Results from series of robot-assisted laparoscopic pyeloplasty.

Study	Number of patients	Access	Mean operative time (min)	Suture time (min)	Mean blood loss (mL)	Mean hospital stay (days)	Complication rate (%)	Success rate (%)	Mean follow-up (months)
Mufarrij *et al.* (2008) [26]	140	Trans	217			2.1	10	95.7	29
Schwentner *et al.* (2007) [27]	92	Trans	108.34	24.8		4.57	3.2	96.7	39.1
Gupta *et al.* (2009) [28]	85	Trans	121	47	45	2.5	3.2	97	13.6
Patel *et al.* (2005) [29]	50	Trans	122	20	40	1.1	2	100	11.7
Palese *et al.* (2005) [30]	38	Trans	225.6	64.2	77.3	2.9	10	94.7	12.2
Mendess Torres *et al.* (2005) [31]	32	Trans	300		52	1.1	6.25	89	8.6
Kaouk *et al.* (2008) [25]	10	Retro	175		50	2	0	100	30

Table 86.3 Results of studies comparing conventional (Lap) to robot-assisted (Rob) laparoscopic pyeloplasty in adults.

Study	Number of patients Lap/Rob	Mean operative time Lap/Rob (min)	Suture time Lap/Rob (min)	Mean blood loss Lap/Rob (mL)	Mean hospital stay Lap/Rob (days)	Complication rate Lap/Rob (n)	Success rate Lap/Rob (%)
Gettman *et al.* (2002) [34]	6/6	167.5/109	74/41.5	<50/<50	4/4	1/1	83/83
Bernie *et al.* (2005) [35]	7/7	312/324	NA	40/60	3/2.5	2/2	86/86
Bhayani *et al.* (2005) [32]	13/8	210/176		129/107	2.5/2.3	1/1	92/88
Link *et al.* (2006) [33]	10/10	134.8/173.8		Same/NA	2.3/2.3	0/1	90/90
Weise *et al.* (2006) [36]	14/31	299/271 NS	NA/76	< 100/< 100	2.6/2.1	2/2	100/97
Hemal *et al.* (2010) [37]	30/30	148/98		101/40	3.5/2		96.7/100

Nevertheless, robotic pyeloplasty has several limitations and drawbacks. An assistant with laparoscopic skills is needed at the side of the patient for instrument exchange, retraction, and suture passage. There is no tactile feedback and more ports than in conventional laparoscopy may be needed, and as a consequence, the cosmetic result is inferior. Finally, the increased cost of robotic pyeloplasty is the most important disadvantage.

Several studies have analyzed the costs associated with the robotic systems, including their use for pyeloplasty [32, 33]. These costs include capital equipment costs, consumable costs, and calculated depreciation based on case volume and usage of capital equipment. In a financial analysis performed by Link *et al.*, robot-assisted pyeloplasty was 2.7 times more costly than laparoscopic pyeloplasty owing to longer operative time, depreciation of the robot, and higher running costs of consumables [33]. If depreciation were excluded, robotic pyeloplasty would still be 1.7 times more expensive, and only equivalent in terms of cost if laparoscopic pyeloplasty operative time was as long as 6.5 h. Bhayani *et al*. essentially presented the same message when stating that for robotic pyeloplasty to obtain cost equivalence to laparoscopic pyeloplasty, the operating room time would have to be less than 130 min for more than 500 cases per year [32]. These data make robotic economics unfavorable and they are unlikely to improve even in high-volume centers. A similar study from the UK reported that robotic pyeloplasty was only 1.2 times more costly, despite the fact that hospital stay for robotic pyeloplasty was almost half as long as that for laparoscopic pyeloplasty (1.7 days vs 3 days) [39].

Most laparoscopic and robotic pyeloplasties are performed transperitoneally. This approach allows visualization of clear anatomic landmarks and has the advantage of a larger working space. The retroperitoneal approach is a viable alternative option and may offer an advantage when intraperitoneal adhesions or other pathology are anticipated. In a study by Zhang *et al*., retroperitoneal pyeloplasty was compared with the open approach [40]. The benefits of laparoscopy over open surgery were again evident. Less blood loss (10 mL vs 50 mL), less analgesic requirements (75 mg vs 150 mg of diclofenac), fewer complications (3.6% vs 7.5%), and a shorter hospital stay (7 days vs 9 days) were obtained, while success rates were equally high (98.2% vs 97.5%). Despite these excellent results, the reconstruction of the anastomosis may be harder with this approach, a fact reflected by the increased conversion rates when compared to transperitoneal pyeloplasties [41]. A prospective randomized trial by Shoma *et al*. comparing the two approaches during conventional laparoscopy found no significant differences between the outcomes and periprocedural parameters [42]. The only significant difference was the longer operative times necessary for the retroperitoneal approach. The limited working space may be a problem for robot-assisted retroperitoneal pyeloplasty as well. However, in the largest robot-assisted retroperitoneal pyeloplasty series presented by Kaouk *et al*., all 10 pyeloplasties were successfully completed with a success rate of 100% at a mean follow-up of 30 months [25]. The authors felt that the limited space was not a hindrance, especially with the robot positioned more cephalad.

Secondary pyeloplasty is more challenging due to fibrosis and has a higher failure rate. However, both conventional and robot-assisted laparoscopic pyeloplasty have been performed with low morbidity and can be used as an alternative to open pyeloplasty, with similar rates of success (around 85%) [17, 43, 44].

Other complicated cases of UPJ reconstruction have been performed both with conventional and robot-assisted laparoscopy [45], namely pyeloplasty in a horseshoe [46, 47] or pelvic kidney, UPJ reconstruction in the setting of a retrocaval ureter [48], pyeloplasty with concomitant lithiasis [49], and other upper urinary tract abnormalities. Bilateral pyeloplasties performed concurrently have also been reported [50].

Compared to other minimally invasive techniques, better success rates have been reported with laparoscopic compared to endoscopic techniques [51]. Improved results can be explained by the fact that both open surgery and laparoscopy can address a crossing vessel. When properly selected, endopyelotomy can achieve similar high rates of success. Endoscopic techniques have similar complication rates to laparoscopy, but usually a shorter hospital stay and operative time [52].

Pyeloplasty has been also performed with single-port surgery. Laparoendoscopy single-site (LESS) surgery, although in its infancy, has already found an application in both conventional and robot-assisted laparoscopic pyeloplasty (see Chapter 107). Series of single–port-only pyeloplasties only have not been reported yet. However, initial results from series comprising a wide variety of single-port urologic procedures confirm that pyeloplasty is feasible and safe [53, 54]. More information regarding success rates after appropriate follow-up is required.

Ureterolithotomy/pyelolithotomy

The development of extraperitoneal shock-wave lithotripsy (ESWL) and improvements in endoscopic, ultrasonic, laser, pneumatic, and electrohydraulic lithotripsy devices have greatly reduced the need for open stone extractions. A small number of patients, particularly those with large size or impacted stones, still fail these treatments and may require open removal. In addition, abnormal renal anatomy, such as a pelvic or horseshoe kidney or a double collecting system, may preclude endoscopic management or make it unfavorable. Open removal can also be indicated when there is a concomitant need for a reconstructive procedure such as a pyeloplasty.

Laparoscopic techniques have been used with success [55, 56] and may be considered for the uncommon patient in whom open stone surgery is considered when other first-line treatments (ESWL, endoscopy) fail. The use of robotic technology has helped with reconstruction. Laparoscopy has also been used to guide percutaneous nephrolithotomy (PCNL) in complex stone situations.

It is important to clearly define pelviureteral anatomy prior to the procedure by obtaining an IVP. If the distal ureter or pelvicalyceal system is not adequately visualized, a retrograde pyelogram can be obtained to rule out a concomitant stricture requiring reconstructive surgery.

Technique

With the patient in the supine position, an indwelling 7 F double-pigtail stent is placed under fluoroscopic guidance immediately before the laparoscopic procedure. An open-ended ureteral catheter can be advanced to the level of the stone and used to assist in bypassing the stone with a wire. If a wire cannot be maneuvered past an impacted stone, then the external stent can be left in place and brought out through a council-tipped Foley catheter and secured via a Tuohy–Borst side-arm adapter. Alternatively, the stent can be placed intraoperatively in an antegrade fashion after stone extraction. Some authors are comfortable with not placing a stent at all if the ureterotomy is properly sutured [57].

The patient is positioned on the table according to the location of the stone. A stone located in the upper ureter or renal pelvis is approached with the patient in the lateral position, and port placement is similar to that for conventional or robot-assisted laparoscopic pyeloplasty, which in some cases is performed concomitantly (see Figures 86.5–86.7). For lower ureteral stones, the patient can be maintained in the supine position with the trocars as shown in Figures 86.8 and 86.13.

The line of Toldt is incised as previously described in the region near the stone. Alternatively, a mesocolic approach can be used, particularly in thin patients [58]. The retroperitoneal course of the ureter is exposed once the colon or sigmoid is reflected medially. Tilting the table away from the side of the stone allows the bowel to fall away from the operative field. Gentle grasping or transverse sweeping movements can be used to identify the position of the ureteral calculus, since the stone is usually palpable. During robot-assisted procedures, identification is based on optical cues only. Usually the ureter is visually dilated above the point of obstruction. Radiographic localization of the stone using fluoroscopy may be helpful if the stone is not readily apparent. Following the ureter cranially may lead the surgeon to the UPJ in cases of stones located in the renal pelvis.

Although impacted stones do not easily migrate cranially, it is wise to prevent this by using a double vessel loop. Once the stone is located, the ureter or renal pelvis is opened with laparoscopic or robotic scissors. Some authors propose using a pointed diathermy hook, and the use of electrocautery has been shown not to affect ureteral tissue healing[59]. The incision is made just large enough to allow the stone to be removed intact. By gently milking the ureter, the stone can be delivered through the incision (Figure 86.14 and 86.15). Alternatively, forceps or a rigid grasper can be used to detach the impacted stone from the mucosa. Every attempt should be made to remove the stone in one piece. An organ entrapment sac may be used for large stones. Stone fragments are retrieved using baskets through a flexible auxiliary cystoscope.

An internal stent should be positioned in patients in whom a preoperative stent could not be passed beyond the stone. This is accomplished by passing a wire through the external stent and guiding it under direct vision up the proximal ureter. The external stent is removed and an indwelling double pigtail stent can be passed over the wire. Correct positioning should be verified cystoscopically or radiographically. Alternatively, a

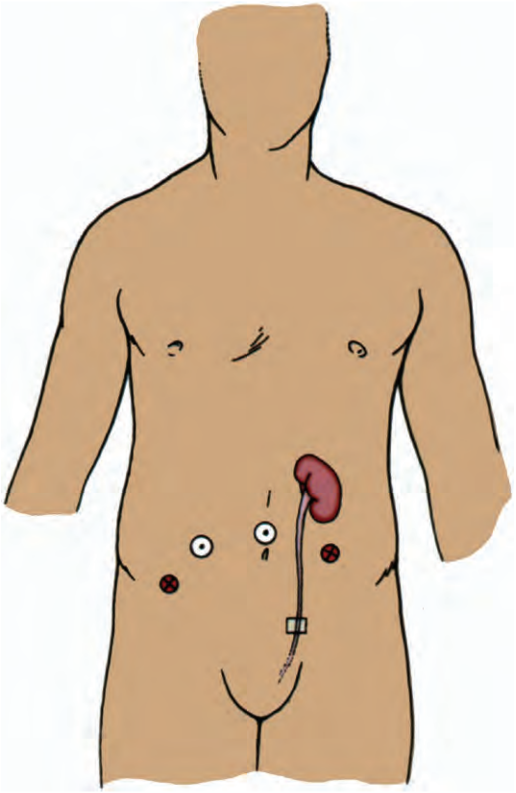

Figure 86.13 Port placement for laparoscopic ureterolithotomy of the left lower ureteral stone. The 10-mm port should be placed contralateral to the side to be approached.

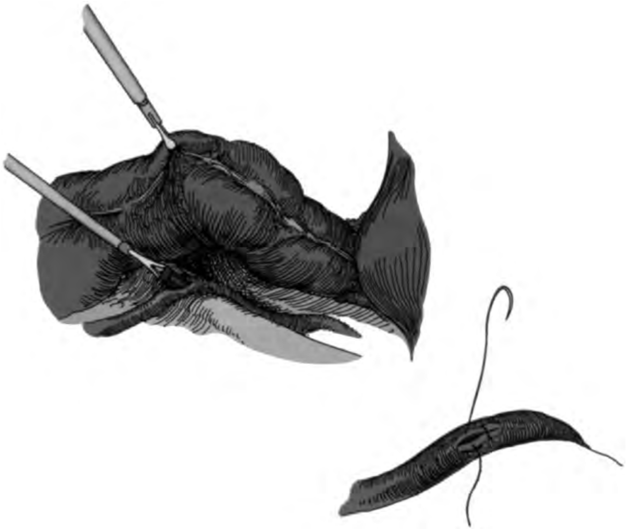

Figure 86.14 Stone is delivered through a ureteral incision and the ureterotomy is closed with interrupted sutures.

stent can be placed in an antegrade fashion, as described for pyeloplasty.

The ureterotomy can be loosely reapproximated over the ureteral catheter using interrupted 4-0 Vicryl sutures. Alternatively, if the incision is less than 1 cm, it may be left open to heal over the stent. A urethral catheter is placed. A retroperitoneal suction drain is placed in a fashion similar to that described for laparoscopic pyeloplasty.

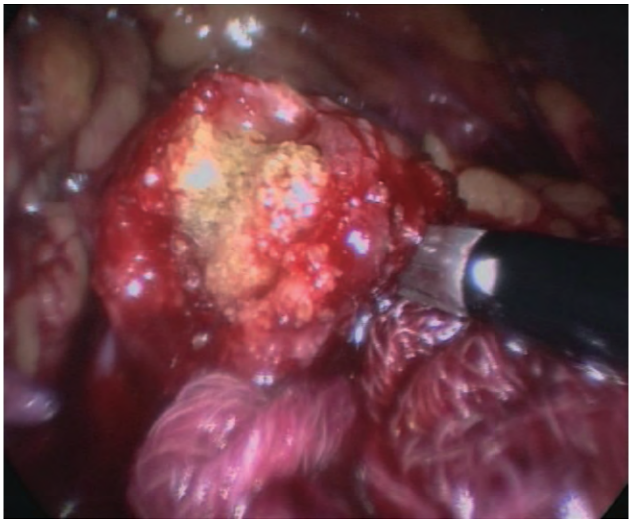

Figure 86.15 Delivery of the impacted middle ureteral stone during transperitoneal laparoscopic uereterolithotomy.

For the retroperitoneal technique, the patient is in the flank position. A small incision is made at the tip of the 12th rib, through which the retroperitoneal space is balloon dissected. If the stone is located lower than this, the balloon dissector is repositioned so dissection continues more distally. The first port is placed in this incision. Two more ports are placed with a combination of direct vision and manual guidance. Port location for both conventional and robot-assisted laparoscopic upper ureteral stone management is similar to that proposed for pyeloplasty (see Figure 86.10). After balloon dissection, the stone location is usually evident and little further dissection is needed to reach the bulging ureter. The ureter again can be used as a guideline to reach the renal pelvis. The following steps for removing the stone are similar to those followed in the transabdominal approach. For lower ureteral stones, the patient is placed in a supine position with the trocars placed as described for any case involving lower ureteral surgery (see Figure 86.8).

Once drainage becomes minimal, the drain should be removed. The stent is removed 4–6 weeks postoperatively. Follow-up study includes an IVP at 3 and 6 months after stent removal.

Results

A laparoscopic approach is rarely (1.1%) [60] needed in patients requiring stone removal. Experience with laparoscopic ureterolithotomy is adequate (Table 86.4) [59, 61–65]. Stone-free rates are high and complication rates

Table 86.4 Results of laparoscopic ureterolithotomy series.

Study	Number of patients	Access	Stone location	Mean stone size (cm)	Success rates (%)	Complication rate (%)	Mean operative time (min)	Mean estimated blood loss (mL)	Mean hospital stay (days)
Gaur *et al.* 2002 [59]	101	Retro	U/M/L	1.6	92	31	79	25	3.5
El Moula *et al.* 2008 [61]	74	Retro/trans	U/M/L	1.8	94.6	0	58.7	90.6	4.1
Flasko *et al.* 2005 [62]	73	Retro/trans	U/M/L		98.7	0	45		3
Kijvikai *et al.* 2006 [57]	30	Retro	U	1.9	96.6	0	121.3		
El Feel *et al.* 2007 [63]	25	Trans	U/M		100	0	145	62.5	4.1
Feayaerts *et al.* 2001 [64]	24	Retro/trans	U/M	1.1	95.4	8.3	111		3.8
Wen *et al.* 2010 [65]	20	Retro	U/M		100	0	38.2		2.5

U, upper; M, mid; L, lower.

low. The most common complication reported is prolonged urinary leak, especially when the lithotomy has been left open and is not sutured.

Laparoscopic ureterolithotomy can be performed with success using either the transperitoneal or retroperitoneal approach. In a comparative study of 35 patients, the retroperitoneal approach was associated with significantly longer operative times (102 min vs 75 min) due to the longer time taken to access the operative field and suturing [66]. This reflects the difficulties that may be experienced if the surgeon is not familiar with this approach. No statistical differences were observed for any other parameters or success rates. However, with experience the retroperitoneal approach can be equally efficient. In a study evaluating the learning curve of retroperitoneal laparoscopic ureterolithotomy, the first 20 patients undergoing this procedure were compared with the next 20 [67]. Operative time significantly decreased (120 min vs 65 min), as well as complication (15% vs 0%) and conversion rates (10% vs 0%). Similarly excellent results have been obtained with retroperitoneal pyelolithotomy. In a study comparing retroperitoneal and transperitoneal pyelolithotomy, stone-free rates and clinical outcomes were similar; however, the retroperitoneal access was associated with a shorter operative time, a faster time to oral intake, and a shorter hospital stay [68].

Laparoscopic stone removal can also be used for large recurrent ureteral stones previously treated with open ureterolithotomy, although dissection may be harder [69]. Stenting during laparoscopic ureterolithotomy and pyelolithotomy is not necessary if adequate suturing is performed; however, prolonged urine leak can be anticipated [70].

Laparoscopic pyelolithotomy is rarely performed due to the high effectiveness of PCNL. However, when concomitant pyeloplasty is required, a laparoscopic approach is well established. Before UPJ repair, stones are extracted through a small pyelotomy that is incorporated into the final pyeloplasty incision. Stone-free rates are high (>80%) [71, 72]. Large pelvic and partial staghorn stones have been successfully treated with laparoscopy; however, stone-free rates for complete staghorn stones are inferior. Pelvic stones in ectopic kidneys can be retrieved laparoscopically as well [73, 74].

Laparoscopic ureterolithotomy has been compared to other minimally invasive techniques. In studies comparing laparoscopic ureterolithotomy to ureterolithotripsy for stones larger than 1.5 cm, operative time and hospital stay were significantly longer for laparoscopy and there were more complications, but stone-free rates at 4 weeks postoperatively were better (100% vs 77.5%) with this approach [75, 76]. In a randomized study comparing ureterolithotripsy, percutaneous lithotripsy, and laparoscopy for upper ureteral stone removal, stone-free rates at discharge were 56%, 90%, and 64%, respectively [77]. At 3 weeks postoperatively, success rates were 88%, 86% and 76%, respectively. However, prolonged drainage was seen in 18% and 16% in the percutaneous and laparoscopic groups, respectively. Ureteroscopy was associated with the least morbidity compared to the other two approaches.

When compared to the open approach, postoperative pain and hospital stay were significantly less with laparoscopy, while operating times, estimated blood loss (EBL), complication and success rates were similar [78].

When comparing laparoscopic pyelolithotomy with PCNL, operative times were significantly longer for laparoscopy (129 min vs 75 min), but complications (12% vs 18%), hospital stay (6.5 days vs 5.6 days) and stone-free rates (88% vs 82%) were similar [79]. When evaluating all these comparative studies, their retrospective nature, the limited number of patients involved, and the diversity of stone size, location, and indications must be kept in mind. Experience among various authors and instrumentation between institutions may vary significantly, influencing final outcomes.

Experience with robotic laparoscopic ureterolithotomy/pyelolithotomy is limited, but results are encouraging. This procedure is feasible and safe given the reconstructive capabilities of the robotic system. This technique is in its early stage of implementation and randomized trials comparing robot-assisted outcomes with other minimally invasive techniques are needed to define clinical efficacy as it pertains to subsets of patients with variable stone size, location, and consistency. Operative times from small series of 6–13 patients vary from 158 to 315 min, while conversion was needed only once. Complications were not reported and stones were removed in all but two cases, including a complete staghorn stone [80, 81].

Laparoscopic management of stones can be used in association with endoscopic techniques. PCNL or ureterolithotripsy have been performed under laparoscopic guidance [82, 83].

Laparoscopic ureterolithotomy has been also performed with single-port surgery. LESS, although in its infancy, has already found an application in conventional laparoscopic ureterolithotomy (see Chapter 107). Series of single-port only ureterolithotomies have not been reported yet. However, initial results from series comprising a wide variety of single-port urologic procedures confirm that stone management is feasible and LESS is safe [84]. More information regarding success rates after appropriate follow-up is required.

Ureterolysis

Retroperitoneal fibrosis is an inflammatory condition of the retroperitoneum that occurs as either a primary (idiopathic) form or secondary to conditions such as inflammatory bowel disease, endometriosis, radiation therapy, neoplasm, vascular aneurysms, or drug therapy (i.e. methysergide) [85]. The goals of ureterolysis include relief of ureteral entrapment, preservation of renal function, prevention of recurrent obstruction, and diagnosis of underlying pathologic causes.

To evaluate the extent of retroperitoneal disease and to rule out the possibility of occult malignancy, a CT scan of the abdomen and pelvis with oral and intravenous contrast must be obtained. An MRI can alternatively be ordered. A search for malignant conditions in adult men should include a digital rectal examination, stool guaiac test, prostate-specific antigen (PSA), and a chest X-ray film. Adult women should have a pelvic examination, stool guaiac test, breast examination, mammogram, and chest X-ray film. The addition of a erythrocyte sedimentation rate may provide a tool for following the activity of the inflammatory process. An IVP should be obtained to define the degree of medial ureteral displacement. Renography should be performed to assess the residual function and degree of obstruction on the affected side. A retrograde pyelogram just prior to the laparoscopic procedure may also be helpful to delineate the entire course of the ureter and rule out possible distal ureteral strictures.

Technique

After placement of an indwelling ureteral stent, the patient is positioned in a fashion similar to that described for conventional or robot-assisted laparoscopic pyeloplasty (see Figures 86.5–86.7). A supine position may be used if both ureters are involved. The table can be rotated to allow the bowel to fall out of the operative field. An exdwelling ureteral stent or lighted stent helps in identifying the course of the involved ureter. In experienced hands, an indwelling ureteral catheter is usually sufficient and it should be of sufficient length to allow lateral displacement of the ureter.

A pneumoperitoneum is established and trocars placed as illustrated in Figures 86.5–86.7 to allow access to the upper ureter. An additional 5-mm port may be placed in the anterior axillary line midway between the costal margin and iliac crest. This port aids in retraction during dissection of the ureter. This port alternatively may accommodate the fourth robotic arm through an 8-mm special trocar when robot-assisted surgery is performed.

Surgical steps are identical for conventional and robot-assisted ureterolysis. With the use of grasping forceps and dissecting scissors, the colon is retracted medially and the peritoneal reflection incised across the iliac vessels, ending distal and medial to the medial umbilical ligament. The incision is then extended proximally to the hepatic flexure on the right or splenic flexure on the left. A sweeping motion brings the colon medially and exposes the psoas muscle. It is important to remember that the fibrotic process may retract the ureter over the great vessels. The ureter should be first identified in the portion uninvolved by the fibrotic process. This is usually in the area medial to the medial umbilical ligament near the bladder or proximally in the region of the UPJ.

The assistant or the fourth robotic arm retracts the periureteral tissues laterally, while the surgeon develops a window around the ureter. A right-angled forceps is used to pass a 4-inch piece of umbilical tape around the freed segment of the ureter. The ends of the umbilical tape are fastened together using a single 9-mm clip. This maneuver facilitates retraction of the ureter to aid in dissection. Care must be taken not to pull too vigorously to avoid avulsing the ureter. This is particularly true for robot-assisted laparoscopy due to the lack of tactile feedback.

Every attempt should be made to rule out malignancy as a cause of the obstruction. Biopsies of periureteral tissues must be taken using biopsy forceps and specimens should be sent for frozen and permanent sections.

A combination of blunt and sharp dissection is used to shell the ureter out of the fibrotic process. To prevent compromise of the ureteral blood supply, cauterization should be used with great caution. The gonadal vessels can be involved in the inflammatory process and should be dissected off the ureter. If necessary, they may be clipped and transected. The dissection is continued until the ureter is freed from the renal pelvis to below the fibrotic process.

Once the ureter is free, it is necessary to isolate it from the fibrotic process. The medial and lateral cut edges of the peritoneum are reapproximated after the ureter is transposed into the peritoneal cavity. A hernia stapler or suture placement can be used to reapproximate the incised peritoneal edges (Figure 86.16). Using an Endo-GIA stapler inserted through the umbilical port or another 12-mm assistant port to split the omentum, an omental wrap can be created. The tissue is used to create a sleeve that can be positioned around the ureter and secured to itself using 9-mm clips or 3.0 Vicryl sutures. Drains are not necessary if the procedure was uncomplicated.

An IVP is performed 2 weeks following surgery, at which time the ureteral stent is removed. Follow-up radiographic studies (IVP and diuretic renal scan) are then obtained at 3, 6, and 12 months postoperatively. Regular activities are resumed after removal of the stent.

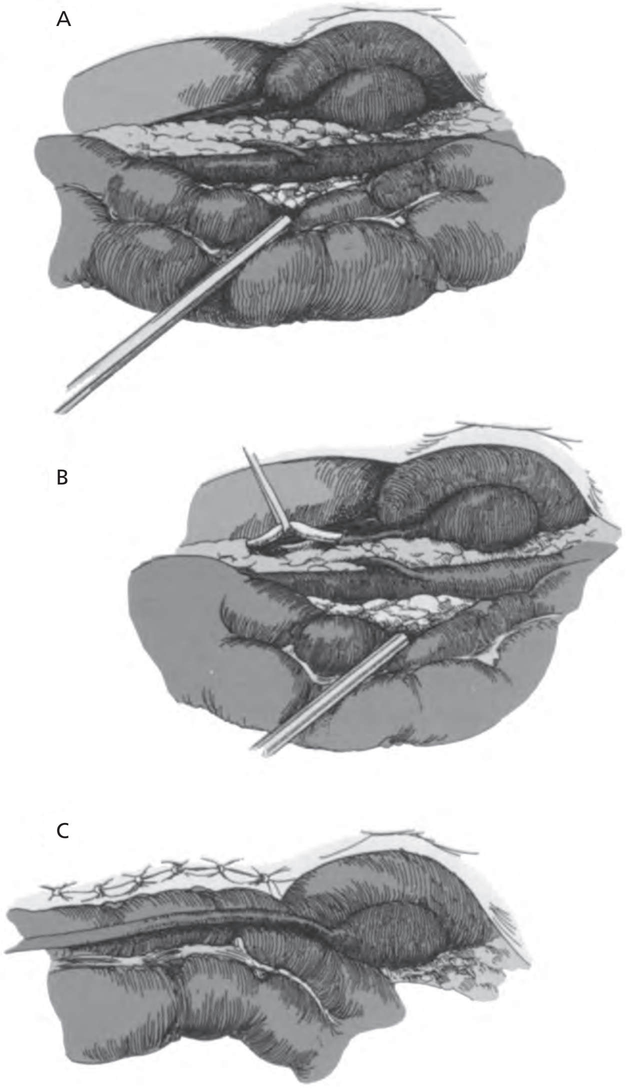

Figure 86.16 (A) Incision of the peritoneum and medial retraction of the colon to expose retroperitoneal fibrosis with the encased right ureter. (B) Umbilical tape aids in retraction for dissection of the ureter. (C) Ureter is intraperitonealized and the cut edges of the peritoneum are reapproximated.

Results

Idiopathic retroperitoneal fibrosis is rare and medical management with steroids, immunosuppressants, tamoxifen, and other drugs is often successful. Thus, large series of laparoscopic ureterolysis are scarce.

In the largest series, 34 patients undergoing laparoscopic ureterolysis were compared to 36 patients undergoing an open procedure [86]. Operative times, EBL, hospital stay, complication and success rates were similar between the two groups; however, in a subgroup analysis performed for patients with primary retroperitoneal fibrosis, those undergoing the laparoscopic approach had a significantly shorter hospital stay (3.4 days vs 10.8 days) and were significantly less likely to require a transfusion (3.7% vs 13.7%). Of note is the fact that ureterolysis can be a very challenging procedure and therefore conversion was required in 17.6% of this cohort. Injury to adjacent vessels and the ureter are the most common complications.

Due to the difficulty of this procedure, hand-assisted laparoscopic ureterolysis has been used with success. In a series of five patients, one minor intraoperative ureteral injury was noted and no postoperative complications occurred. Mean operative time was 259 min, while success after 22.4 months was 90%. The authors considered this approach was easier and faster than pure laparoscopy [87].

Robot-assisted laparoscopic ureterolysis has been reported, but experience is small. In a series of five patients mean operative time was 220.5 min for unilateral ureterolysis and 390 min for bilateral ureterolysis. Mean EBL was 33.5 mL, mean hospital stay was 2.8 days, and after a follow-up period of 5.6 months success was 100% [88]. Thus, robot-assisted ureterolysis and omental wrap is feasible and safe, and compares favorably to the pure laparoscopic technique. In a comparative study from the same institution, five patients underwent laparoscopic ureterolysis and five robot-assisted ureterolysis [89]. Mean operative times for bilateral and unilateral laparoscopic ureterolysis were 509.0 min and 110 min, and the mean EBL was 362.5 mL and 50 mL, and for bilateral and unilateral robot-assisted ureterolysis, 390 min and 220.5 min, and 25 mL and 35.5 mL, respectively. With a mean follow-up of 15.6 months, 90% of all patients were asymptomatic and 86.7% of renal units had no signs of obstruction on imaging. No meaningful differences were deduced from this small series of patients.

Long-term success can be excellent. After 37.5 months of follow-up, success remained at 100% for six patients undergoing laparoscopic ureterolysis [90].

Although bilateral ureterolysis in one setting is possible, performing prophylactic contralateral ureterolysis is under debate. In Fugita *et al.*'s series of 13 patients, no patient with unilateral disease developed contralateral ureteral involvement at a mean follow-up of 23 months, supporting ureterolysis only when ureteral involvement is present [91].

Ureterovesical reimplantation

Open ureteral reimplantation is performed in children for vesicoureteral reflux. In adults, a refluxing anastomosis is usually performed for the treatment of distal ureteral strictures or endometriosis where endoscopic therapy is inappropriate or has failed. Strictures can be the result of a ureteral injury occurring usually during gynecologic surgery or secondary to impacted ureteral stones treated with multiple ureteroscopies and prolonged ureteral stenting. In all cases, stricture length and location should be determined with appropriate antegrade and retrograde studies. In addition, functional studies should be obtained if there is a question of decreased renal function. Reimplantation is also performed after distal ureterectomy for lower-third ureteral tumors when a decision is made for nephron-sparing surgery or for reimplantation of a megaureter in association with ureteral tapering.

Technique

With the patient in a supine position, flexible cystoscopy is performed and a ureteral stent is placed in the ureter if possible. For this reason, the genitalia must always be prepared into the operative field. If retrograde stenting is not possible, a nephrostomy tube may temporarily relieve renal obstruction.

A transperitoneal approach is usually preferred. The pneumoperitoneum is obtained in the standard fashion, and three to four ports are usually used. One 10-mm port for the camera (5 mm for children) is placed just below the umbilicus, while two working ports (10–12 mm or 3 mm) or the two robotic arms (8-mm ports) are positioned in the lower quadrant in the mid-clavicular line and 1 inch below the umbilicus. A fourth trocar (3–5 mm or 12 mm for the robot-assisted procedure) is placed suprapubically or in the contralateral lower quadrant (see Figures 86.8 and 86.13). Alternatively, the three working ports can be placed along an imaginary shallow Pfannenstiel incision; two lateral at the mid-clavicular line and one in the midline. The advantage of this configuration is that it allows for inconspicuous conversion. With the surgeon on the contralateral side, the colon is flexed, and the ureter is identified above the bifurcation of the iliac vessels and dissected caudally. Once the ureter becomes entrapped in scar tissue, it is transected, taking care to excise any nonviable tissue. The healthy ureter is then sharply spatulated posteriorly.

The bladder is filled with 200 mL of normal saline, and the overlying peritoneum is divided between the obliterated umbilical ligaments. This allows entrance into the space of Retzius, and the bladder can then subsequently be further mobilized by dividing anterolateral attachments. When performing a bladder dome advancement technique, no further mobilization is typically necessary. When performing a psoas hitch for longer strictures, the contralateral bladder pedicle may need to be divided before suturing the bladder to the ipsilateral psoas tendon. The ipsilateral anterior bladder wall is then opened transversely (2–3 cm), one-third of the distance from the dome to the bladder neck. A Boari flap procedure can then be performed using the anterior bladder flap created as in open surgery. The middle portion of the posterior flap is then sewn to the apex of the spatulated ureter. Suturing the anastomosis is performed with interrupted or continuous 4-0 polyglactin sutures. Once the posterior anastomosis is completed, a ureteral stent is passed proximally over a guidewire that is placed through an inferior trocar. When the stent cannot be directed into the proximal ureter secondary to a poor angle, it may be passed transurethrally with the flexible cystoscope or percutaneously through a large bore angiocatheter. With the ureteral stent in place, the anterior anastomosis is completed, and the remaining bladder is closed in a longitudinal Heineke–Mikulicz fashion. For a psoas hitch procedure, interrupted polydioxanone sutures are used to approximate the bladder dome to the psoas tendon to allow for a tension-free vesicoureteral anastomosis. Finally, the anastomosis is checked by instilling 300 mL of saline into the bladder, and any additional interrupted sutures are placed as necessary.

If the ureter is going to be reimplanted in an antireflux way, the most commonly described technique has been the laparoscopic Lich–Gregoir reimplantation. When the mobilization has reached the bladder wall, scissors score the bladder serosa for 3 cm in a straight line. The bladder musculature is dissected to the mucosal layer, and the flaps of the trough are developed. The dissection proceeds around the ureter onto the lateral and medial aspects of the UVJ, resulting in an inverted Y configuration. At this point, the bladder mucosa can be seen bulging outwards. The ureter is tucked in the tunnel, and the muscle sutured over it with interrupted 3-0 polyglactin 910 at 0.5-cm intervals. The first suture should not be placed at the very end on the inverted Y in order to avoid kinking of the ureteral orifice. The ratio of tunnel length to ureteral diameter should be 5 : 1 [92]. Assessment of the ureteral position is made with the bladder variably distended. Greatly distending the bladder will further flatten the posterior wall, producing a straight ureteral course along the retroperitoneum.

A Jackson–Pratt drain is placed through the lateral 10-mm trocar site, placed on bulb suction, and removed on the second postoperative day when output is usually minimal. The Foley catheter is removed 7 days after cystography reveals no evidence of extravasation and the ureteral stent is subsequently removed at 4–6 weeks later. Renal function and ureterovesical functional patency is evaluated at 3, 6, and 12 months according to surgeon's preference.

Results

Laparoscopic ureteral reimplantation is feasible and safe. The first case of such a procedure in an adult patient was presented by Reddy and Evans [93]. The primary difference between children and adults is that, during dissection, in children the ureter is readily identified due to the paucity of retroperitoneal fat.

As laparoscopic urologists have gained experience, more technically challenging approaches to reimplant the ureter have beenreported. Transvesical cross-trigonal Cohen antireflux ureteroneocystostomy has been performed with success [94]. A recent comparison between adults and children undergoing this procedure showed no significant differences for this procedure in the two populations [95]. Several reports of reimplanting a megaureter after tapering or excisional tailoring exist also [96]. Tapering can be performed both intracorporeally and extracorporeally [97].

The largest series of laparoscopic ureteral reimplantation to date by Seidman *et al.* included 45 consecutive patients with a success rate of 96% during a mean follow-up period of 25.2 months [98]. Mean stricture length was 3.0 cm, while 56% of patients had had previous open abdominal surgery. This might explain the significant complication rate of 15.5% seen in this series. Among them were two inadvertent ureterotomies attributed to the difficult dissection often associated with such cases. According to the authors, ureteral viability and adequate tissue vascularity are paramount for success. All reimplantations were performed in a refluxing manner and no problems were associated with this technique.

In a comparative study between laparoscopic and open reimplantation, functional outcomes were comparable, while laparoscopy offered the advantages of minimal invasive surgery, namely less postoperative analgesics, shorter hospital stay (9.2 days vs 19.1 days), and faster convalescence (2.3 weeks vs 4.2 weeks). However, operative time was longer for laparoscopic ureteral reimplantation (228 min vs 187 min) and a high degree of laparoscopic expertise was necessary [99].

Experience with robot-assisted reimplantation is limited. However, it is feasible and safe. Boari flap reimplantation with or without psoas hitch has been reported [100, 101]. Results were excellent with 100% success after a 15.5-month follow-up, while hospital stay, convalescence, EBL, operative time, and analgesic requirements were comparable to those obtained with conventional laparoscopy. Small series of robotically repaired obstructive megaureters with intracorporeal or extracorporeal ureteric tapering and ureteroneocystostomy have been reported with success as well [102]. Similarly, robot-assisted laparoscopic surgery was applied to patients requiring distal ureterectomy and reimplantation for lower third ureteric tumors [103].

Ureteroureterostomy for the retrocaval ureter

This entity is very rare. The diagnosis is made by IVP with the characteristic S-shaped course of the ureter. Both transperitoneal [104, 105] and retroperitoneal [106] approaches have been reported. This procedure has also been performed with robotic assistance [107].

Technique

After a stent is passed, the patient is placed in a modified right lateral flank position, and after abdominal insufflation with the Veress needle, three ports are placed, one in the umbilicus, one midway between the xiphoid and the umbilical port, and one at the lower midline (see Figure 86.5). For a robot-assisted procedure, the 10-mm port for the camera is inserted in the umbilicus, and the two 8-mm ports for the robotic arms are placed with one under the costal margin in the midclavicular line and the other two-thirds of the way between the anterior superior iliac spine and umbilicus (see Figure 86.7). A further 5-mm port is inserted 3 cm below the camera port for the assistant to perform retraction, suction, and suture handling. The robot is then docked.

Further surgical steps are identical between robotic and pure laparoscopy. The peritoneum is incised at the line of Toldt, the colon is flexed medially, and the ureter is identified and separated from the posterior surface of the vena cava. The proximal ureter is often dilated. The ureter is then divided at the most distal segment of the dilated ureter. The distal ureteral stump is dissected anterior to the vena cava and spatulated. The two ends are sutured either free hand or robotically. A drain is placed and the operation is concluded in the standard fashion.

Postoperatively the drain is removed when the output is minimal; oral intake starts on the first postoperative day, and the patient's activities are advanced as tolerated. Follow-up includes an IVP 3, 6, and 12 months postoperatively.

The retroperitoneal approach starts with balloon dissection of the retroperitoneal space through an incision at the tip of the 12th rib. Working ports are placed in a configuration similar to that used during a retroperitoneal pyeloplasty (see Figure 86.10). The rest of the procedure is identical to the transperitoneal approach.

Results

Both the retroperitoneal [108] and the transperitoneal [109] approaches are feasible and safe. Small series of seven and four patients, respectively, have confirmed the advantages of laparoscopy, such as less postoperative pain, shorter hospital stay, and faster recovery, without compromising surgical outcome. No complications were reported. Experience with reconstructive laparoscopic surgery has allowed surgeons to become faster, significantly reducing operating times to a mean of 128.6 min and 210 min for the retro- and transperitoneal approaches, respectively. A case of pure robotic retrocaval ureter repair has been reported but more data are required before conclusions can be made [110].

Ureteroureterostomy/laparoscopic repair of ureteral injury

Closed injury of the ureter is usually iatrogenic, most often occurring during endoscopic manipulation [111] or laparoscopic gynecologic procedures [112]. Small perforations can heal spontaneously with stenting; larger injuries, however, require definitive repair. Laparoscopy, both pure and robot assisted, allow minimally invasive correction of the injury, either by suturing the ureteral tear or by performing an end-to-end ureteroureteral anastomosis [113, 114].

Although short-term follow-up shows good results, only limited postoperative data are available to define stricture recurrence and other complications [115].

Laparoscopic cutaneous ureterostomy

Cutaneous ureterostomies are performed for palliation from advanced malignant disease. Open surgery is quite morbid in these patients. Placement of nephrostomy tubes has considerably decreased the complication rate. Nevertheless, the quality of life is often poor, with tube changes required and problems arising due to obstruction and dislodgement.

Laparoscopic cutaneous ureterostomy has been reported with good results [116]. The technique is more complex than placing a nephrostomy tube, and Puppo *et al.* suggest that this procedure be offered only when life-expectancy is more than 6 months [117].

The technique involves standard laparoscopic dissection of the ureter, which is cut as low as possible. After the ureter is freed in the abdominal cavity, it is grasped with an endo-Babcock and withdrawn through one of the lateral ports after the abdomen is deflated. The cutaneous ureterostomy nipple is then performed in the usual manner extracorporeally.

Robot-assisted ureterostomy has not been reported, but it is likely that it can be used as well with success.

Anastomoses between the bowel and the ureter

Several case reports of laparoscopic formation of an ileal ureter completely intrabdominally have been reported. In a comparative study, seven patients undergoing laparoscopic ileal ureter formation were compared to seven patients undergoing the same but open procedure [118]. Narcotic analgesic use and time to convalescence were significantly less in the laparoscopic group, while a trend toward shorter hospital stay (5 days vs 8 days, $P = .101$) was also noted in patients in the laparoscopic group. There was no evidence of anastomotic stricture for patients in either group. Despite the small number of patients involved, a significant advantage was noted for postoperative recovery after laparoscopic compared to open ileal interposition.

Alternatively the ileal segment can be managed extracorporeally through a McBurney incision or a 3-cm infraumbilical incision [119]. This decreases operative time, which was reported to be a mean of 195 min. This time is much shorter than the 8 h reported in initial cases [120].

Initial experience of performing an ileal ureter with robotic assistance or with single-port laparoscopy has been reported, but experience is limited [121, 122].

During laparoscopic or robot-assisted radical cystectomy, the ureters are implanted in the ileal neobladder or in the ileal conduit. Technical details concerning ureteroileal anastomosis in this setting are presented above in the laparoscopic cystectomy section.

Despite the fact that bowel reconstruction is frequently performed extracorporeally through a small incision, there are many reports of pure and robot-assisted laparoscopic radical cystectomy and urinary diversion preformed totally intracorporeally [123–127]. Both types of uretероlileal anastomosis, refluxing and nonrefluxing, have been described [128]. Although results concerning ureteroileal anastomosis are not always mentioned and data extraction is difficult, rates of stricture formation and refluxing anastomosis are similar to those seen in open cases during mid-term follow-up. Specific studies evaluating long-term effectiveness of laparoscopically performed ureteroileal anastomosis (conventional and robot assisted) are needed.

Complications

General complications of laparoscopic surgery have been well documented and should always be kept in mind. Complications specific to laparoscopic ureteral reconstruction occur as a result of injury to the ureter and can be minimized by adhering to basic laparoscopic dissection techniques and with experience. Excess traction during dissection can cause ureteral avulsion, especially with robot-assisted surgery due to the lack of tactile feedback. Moreover, prolonged tension in one area can lead to ischemic injury with resultant necrosis, extravasation, and stricture formation. If an anastomosis has been performed, excess manipulation of the ureter can result in disruption of the suture line. At the conclusion of any procedure, the ureter should be carefully inspected to rule out ureteral extravasation.

Vigorous retraction of the ureter can cause proximal or distal migration of an indwelling ureteral stent, resulting in ineffective postoperative drainage. Possible complications from inadequate drainage include ureteral fistulas, urinoma formation, and severe postoperative abdominal pain. These may be prevented by using a stent of adequate length, such that retraction will allow both ends to remain in proper position. An abdominal radiograph and cystoscopy should be performed after each procedure to document stent position. Closed drainage can be effective postoperatively if leakage occurs. This usually takes place within 48 h of surgery. Management consists of converting the leak into a controlled fistula by maintaining drainage for at least 1 week. Prior to removing the drain it should be taken off suction to be sure output decreases over 24–48 h.

As in open surgery, care should be taken to perform a tension-free repair to avoid increasing the risk of ureteral stricture. A follow up IVP or renal scan after stent removal is recommended to evaluate if there is stricture formation.

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CHAPTER 87

Laparoscopic and Robotic Techniques for the Management of Pelvic Organ Prolapse

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Introduction

Abdominal surgery for pelvic organ prolapse (POP) has a long history, beginning with procedures to secure the uterus to the anterior abdominal wall (Mayo procedure). Eventually, attempts to create a more natural vaginal axis and to prevent enterocele formation led to the suturing of the vaginal apex directly to the anterior longitudinal ligament of the sacrum. The subsequent addition of a piece of material (usually synthetic) between the vaginal apex and the sacrum led to the contemporary version of the abdominal sacrocolpopexy. In patients desiring a uterine-sparing approach, modifications of the abdominal sacrocolpopexy or uterosacral ligament plication procedures have been proposed. While these procedures have documented efficacy and are applicable to a wide variety of patients, their use has been limited due to their invasiveness and prolonged recovery times.

With the advent of laparoscopic techniques in the 1990s, interest in laparoscopic approaches to prolapse repair surged. The laparoscopic approach offers the success, versatility, and durability of the traditional abdominal repairs with a minimally invasive approach and shortened recovery. As technology has continued to advance, robotic and now laparoendoscopic single-site (LESS) surgery have continued to change the management of POP. In this chapter, we review laparoscopic and robotic approaches to the management of POP and mesh complications.

Laparoscopic uterosacral ligament suspension

The use of the uterosacral ligaments for the treatment of vaginal vault prolapse is well-established [1–3]. In the laparoscopic technique described by Lin *et al.*, the patient is placed in the dorsal lithotomy position [4]. After placement of a Foley catheter, a 10-mm laparoscope is inserted through an intraumbilical vertical incision, and four additional 5-mm incisions are made in the lower abdomen. The two lower incisions are lateral to the deep inferior epigastric vessels, while the upper pair are placed lateral to the rectus abdominis muscle at the level of the umbilicus. The patient is then placed in steep Trendelenburg. The next step is the identification and dissection of both ureters from the pelvic brim to the deep pelvis. This is done to prevent ureteral kinking at the time of suture placement or injury during the vaginal vault suspension. An endoanal sizer is placed in the rectum, while two fingers are placed into the vagina to palpate the ischial spines. The exact location of the ischial spines are visualized laparoscopically. Nonabsorbable figure-of-eight suture are then placed through the uterosacral ligaments at the level of the ischial spines, approximately 2 cm medial to the ischial spine and away from the rectum, and brought through the ipsilateral vaginal apex, avoiding entry into the vaginal canal. During suture placement, the rectum is pushed to the contralateral side to avoid injury. This is performed bilaterally and concomitant repairs may then also be performed.

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Over the last 10 years, the data on laparascopic uterosacral suspension have consisted mainly of case reports and small cohort series. In a retrospective study of 133 patients, Lin *et al*. reported no recurrence of prolapse in 87.2% patients at a mean postoperative follow-up of 3.2 years [5]. The major complication rate was 2.25%. This study is consistent with other smaller series with a 75–100% cure rate at less than 1 year and a complication rate of 2–9.5%, with the most common complication being ureteric injury [6].

In a study comparing 25 laparoscopic to 25 vaginal uterosacral vault suspensions, the laparoscopic route had lower estimated blood loss (EBL) ($P < .0001$), shorter hospital stay ($P < .002$), and no recurrences versus three recurrences in the vaginal group [6]. This technique has also been used in women with a uterus. The procedure is as described above, however, the uterosacral ligaments are sutured together using one purse-string permanent suture through the uterosacral ligaments close to the sacrum and then through the posterior cervical ring. A second permanent suture plicating the uterosacral ligaments together in the midline, 2 cm posterior to the first suture provides additional reinforcement [4]. Several studies suggest that women with cervical elongation greater than 5 cm are at increased risk for failure, citing sensation of symptomatic vaginal bulge from the elongated cervix extending down the vaginal canal [4].

While the literature on laparoscopic uterosacral ligament suspension contains no large-scale, prospective, comparative trials, the results from the above case series combined with the proven history of uterosacral vault suspension via the vaginal approach suggest that this may be a promising addition to the array of procedures used to address pelvic organ prolapse. It may also have a specific role in patients who wish to preserve the uterus and in patients wishing to avoid the use of synthetic mesh.

Laparoscopic sacrocolpopexy and uterine-sparing laparoscopic sacrouteropexy/colposacropexy

Since its introduction by Nezhat in 1994, laparoscopic sacrocolpopexy has undergone several modifications [7]. In the original report, a single piece of Gortex mesh was attached to the posterior vaginal apex and sutured or stapled to the anterior longitudinal ligaments of the sacrum. Since its inception, modifications to the procedure have been made, including the use of anterior and posterior pieces of polypropylene mesh. The procedure can be modified for patients desirous of preserving the uterus by using a single piece of posterior mesh or an anterior Y-shaped piece of mesh and a posterior mesh.

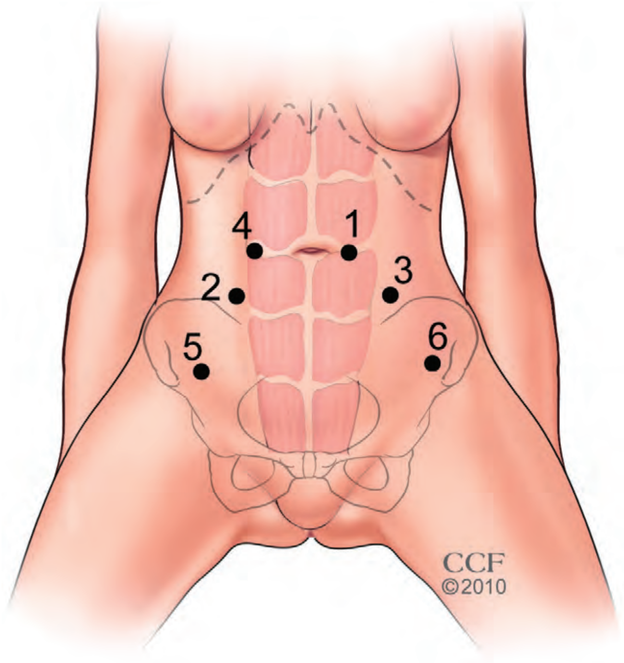

Figure 87.1 Port placements for laparoscopic pelvic organ prolapse surgery. A fifth port (5 mm) may be placed in the left lower quadrant, or a suture may be used to retract the sigmoid colon. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

Most techniques described for laparoscopic sacrocolpopexy involve the same initial steps. With the patient in the dorsal lithotomy position with the arms tucked, four or five ports are placed (Figure 87.1). After obtaining access using either the Hasson open technique or the Verress needle, a 10–12-mm intra- or infra-umbilical port is placed. Two additional 10–12-mm ports are placed lateral to the rectus muscle. One or two additional 5-mm ports are placed 2–3 cm cephalad and 2–3 cm medial to the anterior superior iliac spines, avoiding ilioinguinal and iliohypogatric nerve injury or entrapment. The left lower port is utilized to retract the sigmoid colon to the left and cephalad (Figure 87.2). This port can be eliminated by using a suture to retract the sigmoid. A 1-0 monofilament suture on a large (CT-X) needle can be passed into the left lower quadrant, through an epiploic appendage of the sigmoid colon, and back out through the left lower quadrant, and clamped at the skin level to retract the sigmoid colon.

After the sigmoid is retracted, the sacral promontory, right common iliac artery, and right ureter are identified. The posterior peritoneum over the sacral promontory is incised longitudinally to the level of the vaginal apex. An endoanal sizer is placed in the vagina; thereby reducing the prolapse and elevating the vagina for exposure (Figure 87.3). The peritoneum over the vaginal apex is then incised, and this dissection is continued

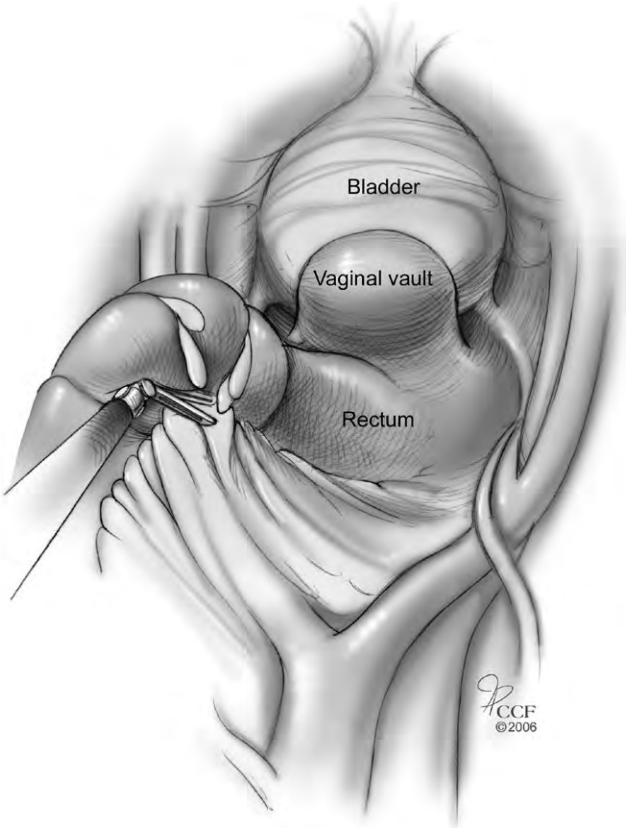

Figure 87.2 Retraction of the small bowel and sigmoid colon allows exposure of the sacral promontory. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

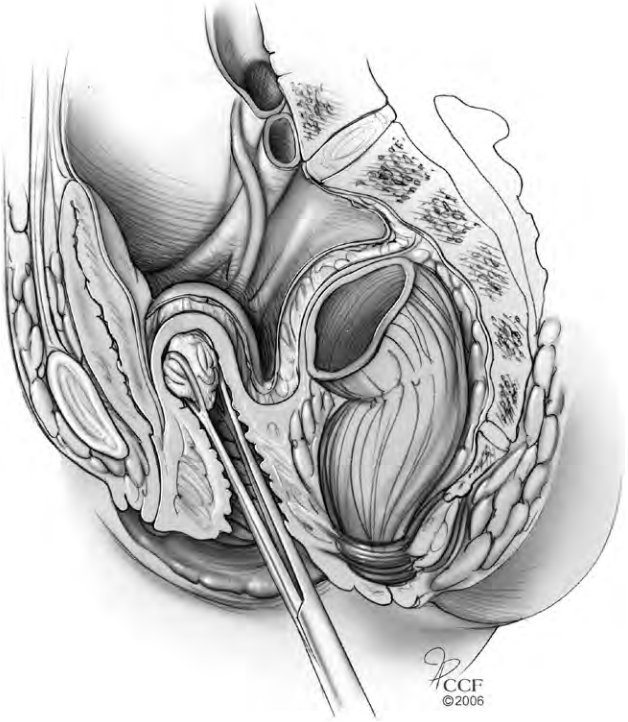

Figure 87.3 Placement of an endoanal sizer in the vagina reduces the prolapse and elevates the vagina for exposure. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

anteriorly along the vaginal wall dissecting the plane between the bladder and vagina (Figure 87.4). The bladder can be filled to help demarcate this plane, or by introducing a cystoscope light into the bladder. This plane is dissected at least 3 cm distal to the vaginal apex to allow space for placement of the anchoring sutures. The lack of direct tactile feedback makes this dissection challenging; resulting in a cystotomy or sutures in the bladder in 10.7% of cases making cystoscopy imperative [8]. Similar dissection is performed on the posterior vaginal wall to deperitonealize this area and separate the vagina from the rectum posteriorly. The mesh, either in two separate strips (3–5 cm x 12–15 cm) or prefashioned in a Y-configuration, is passed into the field and sutured with nonabsorbable suture to the posterior and then the anterior vaginal wall. At least four sutures are required on either side to fully anchor the mesh. With the prolapse reduced via the endoanal sizer, the proximal end of the mesh is anchored to the anterior longitudinal ligament of the sacrum with two or more nonabsorbable sutures (Figure 87.5). The excess mesh is trimmed and the posterior peritoneum is then closed over the mesh (Figure 87.6). Cystoscopy should be performed at the end of the procedure to ensure ureteral patency and that none of the sutures have passed into the bladder.

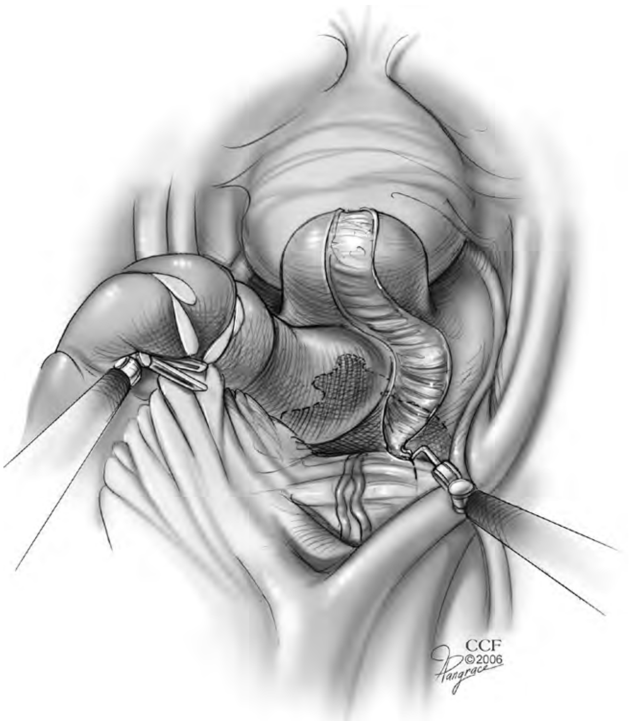

Figure 87.4 Peritoneum over the vagina apex is incised longitudinally to the level of the sacral promontory. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

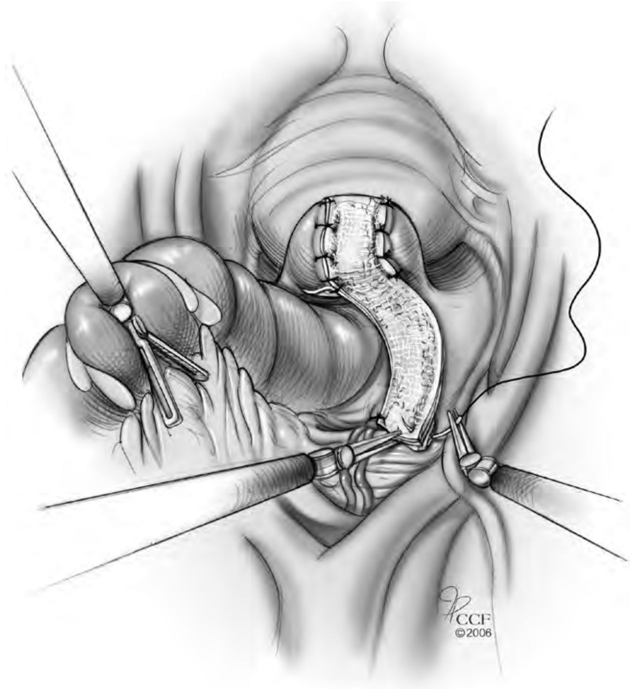

Figure 87.5 Mesh is introduced and sutured to the vaginal apex anteriorly and posteriorly and sutured to the sacral promontory. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

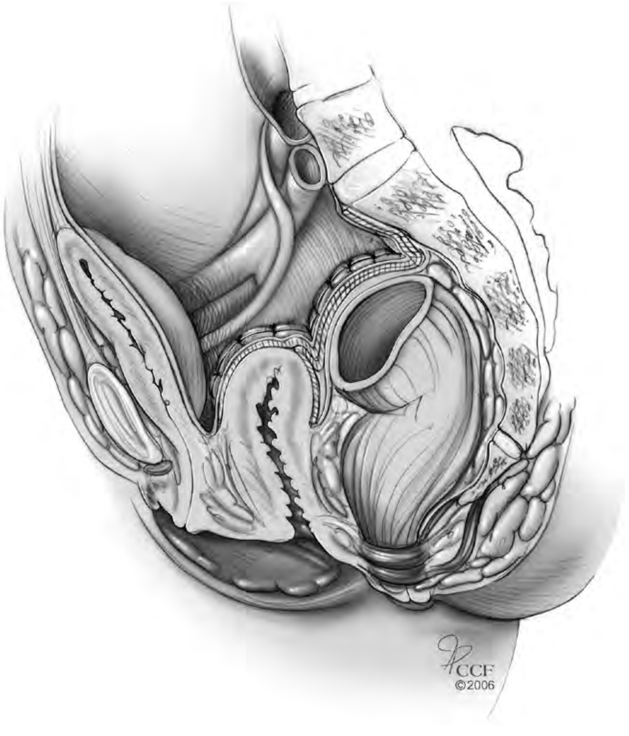

Figure 87.6 Mesh is covered by the posterior peritoneum. The vagina is suspended to the sacral promontory, recreating normal vaginal anatomy. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

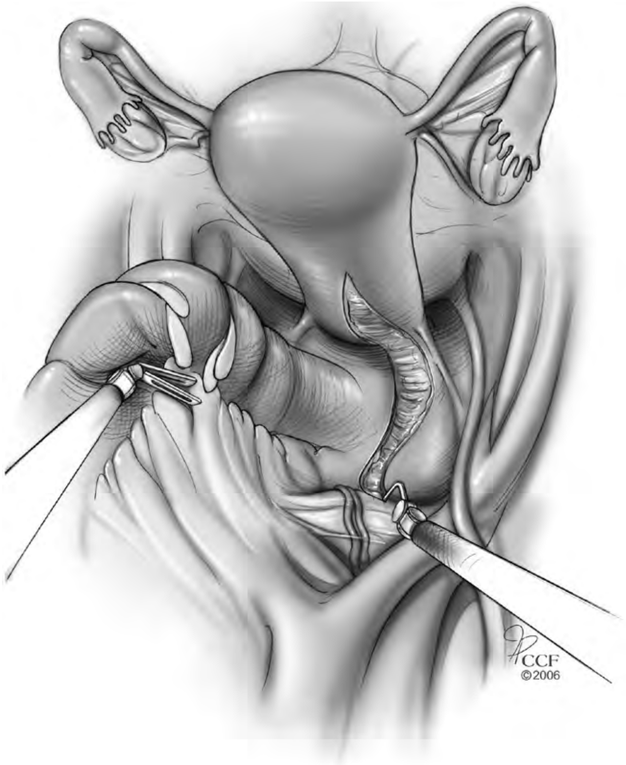

Figure 87.7 In sacrouteropexy, the posterior peritoneum overlying the posterior vaginal cuff and cervix is incised longitudinally to the level of the sacral promontory. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

In patients undergoing sacrouteropexy, the posterior peritoneum is incised from the level of the sacral promontory, caudally to the level of the posterior vaginal cuff and cervix (Figure 87.7). Depending on surgeon preference, a single piece of posterior mesh (3–5 cm x 12–15 cm) or an anterior Y-shaped piece of mesh and a posterior mesh are used. In cases using a single piece of mesh, the mesh is sutured to the posterior vaginal cuff and posterior cervix using 0-nonabsorbale sutures. When using two pieces of mesh, the posterior mesh is placed as described, while each arm of the anterior Y-shaped mesh is passed through the broad ligament. The mesh(es) are fixed to the sacrum as described above.

Laparoscopic sacrocolpopexy appears to successfully recapitulate the open technique that has demonstrated durable results for several decades. Several studies have demonstrated the laparoscopic approach to be successful, with a 90–96% cure rate and a low mesh erosion rate, ranging from 1% to 8%. [10] The largest series of laparoscopic sacrocolpopexies is a retrospective cohort of 165 patients followed for a mean of 43 months. [11] Of the 165 patients, 27 were lost to follow-up. Success rate at mean follow-up was 94.9%, with 5.07% patients reporting recurrent vaginal vault prolapse and 3.62% a recurrent cystocele.

A comparative cohort study from our institution compared 61 patients treated with open sacrocolpopexy and 56 treated laparoscopically with a mean follow-up of 16 and 14 months, respectively. The mean total operative time was longer for the laparoscopic group (269 min vs 218 min), but hospital stay was shorter in the laparoscopic group (1.8 days vs 4.0 days) [8]. Reoperation rates (11% laparoscopic vs 5% open) and clinical outcomes rates were similar. The sample size was not powered adequately to detect differences in complication rates.

Robotic laparoscopic sacrocolpopexy and sacrouteropexy

This modification of the laparoscopic sacrocolpopexy utilizes the robotic system to facilitate three-dimensional visualization of the operative field, placement of sutures, and tying of the sutures; thereby simplifying the execution of maneuvers and shortening the laparoscopic learning curve. Five ports are typically utilized: an umbilical (intra-, infra- or supra-umbilical) 12-mm camera port; two 8-mm robotic ports placed at the lateral edge of the rectus abdominal muscles (8–10 cm lateral to the camera port) at the level of the umbilicus or 1–2 cm caudal; and traditionally two additional ports, a 5- and a 10-mm or two 10-mm ports, are placed bilaterally 3 cm medial and cephalad to the anterior superior iliac spine to allow an assistant to retract the sigmoid colon and small bowel (see Figure 87.1). At least one of these ports should be 10 mm to allow passage of the mesh strips and needles as needed. In women with small pelvises, we place the accessory 10-mm port 8 cm lateral and 2–3 cm cephalad to the umbilical port. Once access is obtained and the robotic arms positioned, the technique is identical to that described for laparoscopic sacrocolpopexy (see Video 87.1). The robot can be docked between the legs or side docked. As in the laparoscopic procedure, the uterus can be spared by performing a robotic sacrouteropexy as described above.

Several studies have demonstrated the feasibility of this procedure with excellent short-term results. Ayav *et al.*, in a series of 18 patients at 6-month follow-up, reported that none had recurrent prolapse in any compartment [12]. Similarly, Dimarco *et al*. followed five women for a mean follow-up of 4 months with no recurrent anterior, posterior, or apical prolapses [13]. Elliot *et al*. followed 21 patients for 1 year and reported a 95% apical cure rate and a 100% subjective surgical satisfaction rate [13]. Two more recent larger series by Akl *et al.* and Shariati *et al*., who followed 80 and 77 patients undergoing robotic sacrocolpopexy, respectively reported recurrent prolapse in 3.7% and 1.29% of patients, respectively [14]. Intra- and post-operative complications rates are low. In the largest study to date, Akl *et al*. reported a 1.2% cystotomy rate, 1.2% ureteric injury rate, 1.2% enterotomy rate, 1.2% postoperatve ileus rate, and 6% mesh erosion rate [14].

In a retrospective study comparing 73 robot-assisted sacrocolpopexies with 10 open abdominal sacrocolpopexies 6 weeks postoperatively, Geller *et al*. found the robotic group to have slightly better POP-Q "C" points, –9 compared with –8 ($P = .008$) [15]. All other anatomic outcomes were similar. Robotic procedures had statistically less blood loss (103 ± 96 mL vs 255 ± 155 mL, $P < .001$), longer total operative time (328 ± 55 min vs 225 ± 61 min, $P < .001$), shorter length of stay (1.3 ± 0.8 days vs 2.7 ± 1.4 days, $P < .001$), and a higher incidence of postoperative fever (4.1% vs 0.0%, $P = .04$) [15]. At the 31st Annual American Urogynecological Society Meeting, Paraiso et al. presented an abstract on the on the first randomized controlled trial comparing robotic to laparscopic sacrocolpopexy. The initial findings at 1 year showed similar anatomical and functional outcomes with the robotic sacrcolopexy being more expensive, and requiring longer operating times. [9].

Laparoscopic-assisted percutaneous vaginal tape vault suspension and uterine suspension procedures

Besides the obvious benefits in recovery time and incision size, one of the benefits of laparoscopy in pelvic surgery is the ability to visualize internal anatomy while working on an external structure. This principle was utilized in creating the laparoscopic-assisted percutaneous vaginal tape vault suspension (Lap PVT-VS; Figure 87.8) and subsequently, the uterine suspension procedure, Lap PVT-US; Figure 87.9) at the Cleveland Clinic (see Video 87.2). In these novel procedures, the surgeon, operating vaginally, passes a strip of synthetic mesh percutaneously under the lateral walls of the vagina using angled trocar needles, while monitoring the needle's passage both with vaginal inspection and laparoscopic visualization. In order to avoid bladder and bowel injury, as well as to allow use of the technique in a uterine-sparing fashion, the mesh strips are passed along the lateral walls of the vagina. This allows the mesh to provide support along the full length of the vagina, rather than just supporting the apex as in other sacrocolpopexy procedures; consequently, fewer concomitant transvaginal procedures (perineal body repairs, rectocele repairs) are required [8].

The initial steps of this procedure are identical to the laparoscopic sacrocolpopexy. After the peritoneum over the sacral promontory and down toward the vaginal apex has been incised, the prolapse is reduced with a bivalve speculum. Two small stab incisions are made in the labial folds just lateral to the vagina at the 4 and 8 o'clock positions near the perineal body (Figure 87.8). Strips of polypropylene mesh, cut 20 cm long and 15 mm wide, are passed using trocar needles with a suture tied

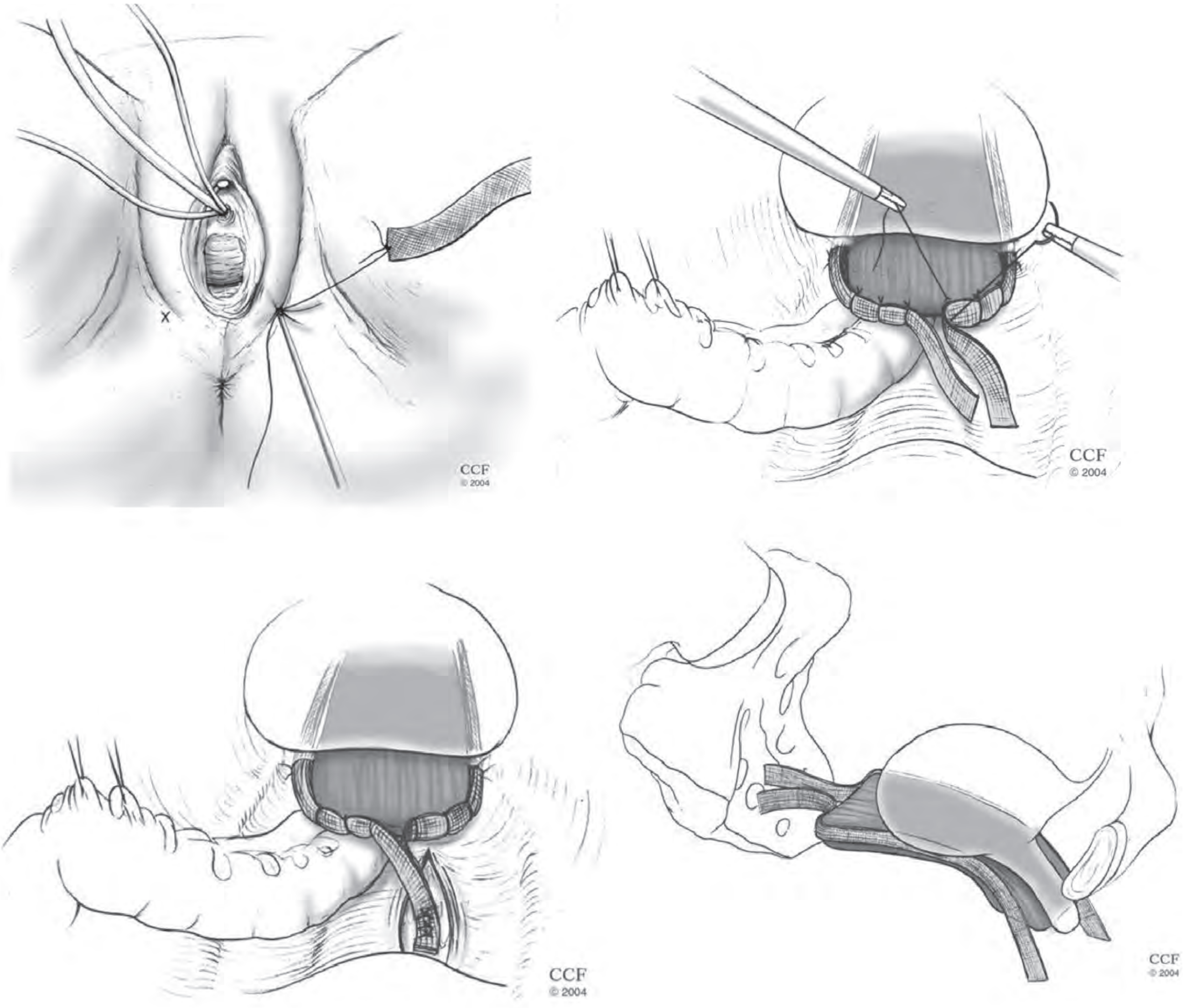

Figure 87.8 Laparoscopic percutaneous vaginal vault suspension procedure. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

to the mesh. Care is taken to pass these in the plane below the full thickness of the vaginal wall; inadvertent button-holing of the vaginal wall may easily be managed by pulling back and redirecting the needle. The laparoscopic view is used to help direct the mesh toward the area just lateral to the vaginal apex, where the trocar needles are passed into the abdomen. The mesh is then grasped laparoscopically and pulled into the laparoscopic field. The mesh strips are left along the entire length of the vagina, and trimmed at the level of the labial skin. Each mesh strip then requires only one stitch to hold it in place, as local tissue reaction to the mesh will fix it in place within 2 weeks, similar to sling fixations for urethral support procedures (Figure 87.8). A third stitch is thrown near the apex, joining both mesh strips to each other and to the vaginal muscularis. With the prolapse reduced, the proximal end of the mesh is fixed to the anterior longitudinal ligament of the sacrum as in the traditional approach. Figure 87.8 shows the proper placement of the mesh along the lateral vaginal walls, noting the relation to the cervix in a uterine-sparing case.

To date we have performed this procedure on 58 patients; analysis of the first 32 cases with a mean follow-up of 10 months revealed a mean total operating room time of 234 min. Concomitant repairs were infrequent, with seven patients undergoing transvaginal posterior colporrhaphy or perineorrhaphy. No bowel or bladder injuries were noted; complications consisted of a deep vein thrombosis in one patient and a port site hernia in another; two patients (6.25%) required a transvaginal anterior colporrhaphy for recurrent anterior wall prolapse [8]. We are currently collecting long-term follow-up data, including POP-Q scores and sexual function questionnaires. The initial results are very promising for this being a minimally invasive, safe, and

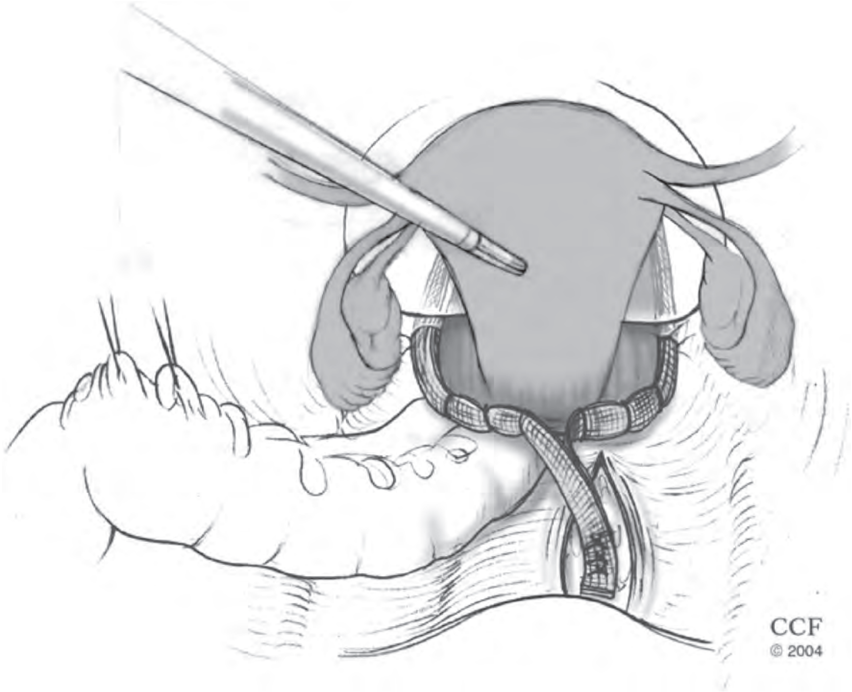

Figure 87.9 Laparoscopic percutaneous vaginal uterine suspension procedure. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2004–2010. All Rights Reserved.)

easily learned technique with post-hysterectomy and uterine-sparing applications.

Laparoendoscopic single-site sacrocolpopexy

With improved technology and surgeon experience, laparoscopic surgery through a single incision has become possible. LESS has been used for oncologic renal, prostate, and reconstructive surgery. Pelvic organ prolapse surgery has been added to this growing list of applications.

With the patient in the dorsal lithotomy position with the arms tucked, a 1.5-cm semi-circular incision is made at the inner edge of the umbilicus. Using the Hassan technique, the rectus fascia is incised and four 0-Vicryl fascial sutures are placed to fix the port in place and prevent subcutaneous emphysema. The multichannel port is placed in the incision and secured using the fascial sutures. A 5-mm flexible laparoscope is placed in the camera port. The laparoscopic procedure is performed using the same technique as described previously.

At our institution, 11 cases were performed and nine patients (82%) consented to participate in the study. The mean patient age was 61.6 years (range 39–75 years) with follow-up from 1.3 to –11.7 months. Four (44%) had a uterine-sparing procedure and five (56%) underwent a concomitant sling or cystocele repair. All had at least stage II pelvic organ prolapse. The mean operating time and estimated blood loss were 187 min and 61 mL, respectively. Average length of stay was only 1.4 days, and most patients (78%) had a visual analog pain score of 0 at discharge. Complications included one intraoperative bladder perforation and one wound infection. Two patients required additional surgeries postoperatively. The first patient underwent a cystocele repair and sling at 6 months and the second required a sling at 5 months. Of the four patients who underwent a uterine-sparing procedure, one developed symptomatic uterine prolapse at 9-month follow-up.

Conclusions

Over the last decade new minimally invasive laparoscopic, robotic, and LESS techniques have evolved for the correction of pelvic organ prolapse. All of these techniques aim to achieve the same durable success of the traditional open abdominal techniques, while minimizing recovery, pain, blood loss, and hospital stays. The limited, available data suggest that laparoscopic and robotic outcomes are comparable to those for the open approach in the short term.

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CHAPTER 88

Laparoscopic and Robotic Techniques for Repair of Female Genitourinary Fistulas

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Introduction

Vesicovaginal fistulas usually arise as a complication of gynecologic surgery, especially abdominal or vaginal hysterectomy. Surgeries done for malignant ovarian tumors increase the risk of intraoperative injury to the bladder. Adhesions due to previous infections, endometriosis, and radiotherapy, and infiltration due to malignancy also increase the risk of injury to the urinary bladder as well as the ureter during pelvic surgeries. Other causes of vesicovaginal fistula include radiation for treating pelvic malignancies or as a result of advanced gynecologic malignancies. Vesicovaginal fistulas arising from obstetric accidents, usually obstructed labor or instrumental vaginal delivery, have become rare in the developed world. However, in many less developed countries in the world obstetric fistula is the most common type of vesicovaginal fistula.

In neglected obstructed labor the trigone of the urinary bladder and the bladder neck get wedged between the impacted head and the pubic symphysis. With prolonged ischemia the posterior bladder tissues and the vaginal tissues undergo necrosis, resulting in a vesicovaginal fistula 5–7 days later. They are often large and complex and may involve the bladder neck and upper urethra, thereby threatening the continence mechanism. Sometimes the ureteral orifice may be involved in the scarring, resulting in obstruction and hydroureteronephrosis or a combined vesicovaginal and ureterovaginal fistula. Caesarean hysterectomies done for obstructed labor and rupture of the uterus involving the bladder is the other obstetric situation causing vesicovaginal fistulas. These are caused by ischemic insult as well as direct surgical injury or contusion. Surgical injury to the bladder can also be sustained during difficult caesarean sections, like repeat caesarean sections where the urinary bladder is pulled up by adhesions due to the previous surgery. The resulting fistulas are usually higher up, involving the upper vagina and sometimes the cervix. A bladder injury during caesarean section is the most important cause of a vesicouterine fistula. Improvement in obstetric care is the mainstay in their prevention.

Posthysterectomy vesicovaginal fistula is always the result of an intraoperative injury to the urinary bladder. This may be as trivial as a stitch going inadvertently through the urinary bladder during closure of the vaginal vault. A ureterovaginal fistula may accompany a vesicovaginal fistula or may occur in isolation, and is invariably due to an intraoperative injury to the distal ureter sustained during the pelvic surgery.

Psychologic impact

Whatever the etiology, vesicovaginal fistula has a devastating impact on the social life, sexual function, and self-esteem of the affected woman. The continued contact of urine with the vulva from diapers used to contain the same causes excoriation of the skin and vulvitis. This adds to the ill health of the patient. In the economically poorer countries where most of these fistulas arise from lack of appropriate obstetric care, the patient often cannot afford even diapers. The constant dribble of urine emanates bad odor and the patient becomes a social outcast. The added agony of fetal loss

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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is yet another cause for psychologic upset. Some patients are divorced by their husbands due to their inability to have a healthy sexual relationship. A few patients may actually suffer from depression. Many patients develop amenorrhea due to hypothalamic influence. In a recent study conducted in Nigeria, the incidence of the commonest medical problems present in women with obstetric fistulas were dermatitis (20%), foul smell of urine (15%), recurrent UTI (10%), infertility (5%), amenorrhea (5%), in that order [1]. Socially, 45% of the women interviewed felt ostracized and 50% were economically impoverished by job loss consequent to their developing the fistula. The divorce rate reported in this study was 25%. Therefore, psychologic support and sometimes pharmacotherapy become necessary before embarking on definitive surgery.

Preoperative evaluation

The patient typically presents with incontinence of urine that usually follows delivery or pelvic surgery. Some patients may have an antecedent history of radiation or gynecologic cancer. Usually the patient reports leakage of urine immediately after removal of the catheter following the surgery or obstetric event, but the leakage can start after several days or even a few weeks later. Sometimes, especially in the presence of an isolated ureterovaginal fistula or a small high vesicovaginal fistula, the patient may have a normal voiding pattern in addition to continuous incontinence. Digital vaginal examination helps to identify the fistula and to rule out coexisting pathologies in the pelvis. It also helps assess the accessibility of the fistula for reconstruction through the vagina, extent of fibrosis and associated scarring, and quality of vaginal tissue. A per speculum vaginal examination is needed to accurately identify the presence, number, and location of the fistula. A computed tomography (CT) cystogram demonstrating contrast in the vagina can confirm the presence of a small fistula, that may even have been missed on examination. The three-tampon test described by Moir helps distinguish a vesicovaginal fistula from a ureterovaginal fistula [2]. Cystoscopy is mandatory in every case to assess the number of fistulas, and their size, location, and relationship to the ureteral orifices and bladder neck. It also helps assess the bladder capacity, detect any calculus or foreign body such as suture material, and the presence of any inflammation of the bladder mucosa. A biopsy of the fistula may be essential in cases treated earlier for gynecologic malignancies to rule out presence of cancer. Upper tract function and anatomy is best assessed by CT urography. Twelve percent of vesicovaginal fistulas may be associated with ureteral abnormalities [3]. In case of suspected ureterovaginal fistula or a distal ureteral stricture on imaging, a retrograde ureteropyelogram may be performed just prior to reconstructive surgery for better delineation of the distal ureteral anatomy.

A urine sample for culture must be obtained using a catheter inserted through the urethra or a sterile speculum inserted in the vagina. Any active infection must be treated with appropriate antibiotics. Any indwelling catheter must be removed and tissue edema should be allowed to subside completely, especially in fistulas occurring after delivery. Improving the general condition and nutrition of the patient, correcting anemia, and treating vulval excoriations are important aspects for good healing after surgery. In patients in a hypoestrogenic state, topical application of estrogen creams for a few weeks may improve the quality of vaginal tissues.

Classification of vesicovaginal fistulas

Vesicovaginal fistulas can be classified as simple or complex. The following fistulas are considered as complex:

- Large fistulas;
- Fistulas involving the ureteric orifice, bladder neck or urethra;
- Previous failed repairs;
- Postradiotherapy fistulas;
- Underlying malignancy or granulomatous infections.

Based on their anatomic location, fistulas can also be classified as trigonal or supratrigonal, as seen on cystoscopy, and juxtacervical, high vaginal or mid-vaginal based on the anatomic location on the anterior vaginal wall.

Treatment options for vesicovaginal fistula repair

A period of conservative management by prolonged catheterization for 4–6 weeks may be attempted in fistulas following hysterectomy, but only small fistulas are likely to heal. A decision to start conservative management must be weighed against the good results of early repair, especially in posthysterectomy fistulas. Minimally invasive methods like fulguration of the fistula tract are successful only in a small proportion of cases with small fistulas. There are a few anecdotal reports indicating successful use of biologic sealants like fibrin glue and cyanoacrylic glue for small vesicovaginal fistulas less than 1 cm [4, 5]. The standard treatment remains surgical correction of the fistula.

A period of conservative management of a vesicouterine fistula is justified. Medical management of these fistulas has been attempted with long-acting gonadotrophin-releasing hormone analogs to induce reversible menopause with some success [6, 7]. However, most cases require surgical repair of the fistula. A few ureterovaginal (or ureterouterine) fistulas with a patent distal ureter may be amenable to endourologic management by endoscopic ureteral stenting [8]. Most ureterovaginal fistulas following pelvic surgery are, however, associated with distal ureteral stricture and are best managed surgically as soon as they are detected. In the presence of active infection and sepsis, a period of antibiotic therapy and urinary diversion in the form of a percutaneous nephrostomy on the affected side may be essential to control infection before contemplating definitive reconstruction.

Timing of surgery for vesicovaginal fistula

Traditionally, a waiting period of 3 months or more after the antecedent event has been followed before embarking on fistula repair. However, this has been recently questioned. The advantages of early repair are obvious and include shortening of the duration of morbidity and psychosocial stress caused by urinary incontinence, and reduction in the cost of managing incontinence. While there is now general consensus that if the fistula is detected within 72 h after gynecologic surgery early repair is indicated, there is often a delay of several days for the diagnosis of the vesicovaginal fistula and its further evaluation. Several reports have shown that fistula repair can be performed within 6 weeks with safety and efficacy [9, 10]. Nagaraj *et al*. have shown that even early laparoscopic repair of a posthysterectomy fistula can be done safely and efficaciously [11]. While we consider that early repair in gynecologic fistulas is justified, there is a lack of uniform consensus regarding the timing of repair.

In the case of obstetric fistulas, we consider it is prudent to wait for at least 6 weeks before performing the repair. This may be justified because the extent of trauma to the bladder and the vagina is difficult to assess at the time of the event. Furthermore, during puerperium there is a phase of negative nitrogen balance that is a part of the normal involution of the pelvic viscera. Nevertheless, it may be noted that a large series from Nigeria has reported a high success rate with early repair even in obstetric fistulas [12].

Principles of repair

The principles of vesicovaginal fistula repair have largely remained unchanged over decades. These include adequate exposure, adequate separation of bladder and vagina, trimming of any devascularized edges of the bladder and vagina, tension-free closure of the bladder and vagina with nonoverlapping suture lines, interposition of vascularized tissue (omentum, peritoneum or Martius flap), and adequate postoperative bladder drainage. In case the ureteral orifice is involved or in the presence of a coexistent ureterovaginal fistula or stricture, ureteral reimplantation is required. Attention must also be paid to the continence mechanism when the fistula involves the urethra or bladder neck or where the bladder capacity is compromised. With the high success rate associated with surgical repairs, attention must also be given to maintaining the vaginal luminal size during reconstruction to retain sexual function [13]. Continence procedures, like a pubovaginal sling in cases of extensive urethral involvement, augmentation cystoplasty for a small bladder, or vaginoplasty for vaginal stenosis, may be required in select cases.

Surgical approaches to repair and indications for an abdominal approach

Surgical repair of a vesicovaginal fistula can be performed through the vaginal or abdominal routes. The absolute indications for an abdominal approach are when the vesicovaginal fistula is associated with:

- Involvement of the ureteral orifice by the fistula;
- A small capacity bladder requiring augmentation;
- Vaginal stenosis from postsurgical scarring or previous radiation;
- Involvement of the cervix or uterus;
- Coexistent ureterovaginal fistula or ureteral stricture requiring ureteral reimplantation.

Vesicouterine or vesicocervical fistulas can only be repaired through the abdominal route. A large supratrigonal vesicovaginal fistula or a previously failed vaginal repair are relative indications for abdominal repair.

Most general urologists prefer the abdominal approach as they are more familiar with the pelvic anatomy, whereas urogynecologists prefer the vaginal approach. The advantages of the vaginal approach include less postoperative pain, less postoperative ileus, avoidance of the complications of a laparotomy, and better cosmesis.

Recently, laparoscopic and robot-assisted laparoscopic methods have been used to decrease the morbidity of an abdominal repair of a vesicovaginal fistula. These techniques have the advantages of reducing the morbidity of surgery by reducing postoperative pain, early resumption of feeding, early ambulation, shorter hospital stay, and better cosmesis as compared to open surgery. These techniques are challenging and there exists a steep learning curve, especially for the purely laparoscopic technique. Robotic assistance using the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) has the advantages of depth perception due to a three-dimensional view, magnification, motion scaling, tremor filtration, and improved dexterity due to the EndoWrist™ technology at the end of the robotic working instruments, permitting movement with seven degrees of freedom. Robotic assistance thus greatly facilitates laparoscopic repair of vesicovaginal fistula.

Indications for laparoscopic or robot-assisted laparoscopic repair of a vesicovaginal fistula

Any patient with a vesicovaginal fistula in whom an abdominal approach to repair is planned is potentially a candidate for undergoing laparoscopic repair of the vesicovaginal fistula. Patients must not have comorbidities that contraindicate laparoscopic procedures, like severe pulmonary or cardiovascular disease or uncontrolled bleeding diathesis. Prior abdominal surgery or a previously failed repair is not a contraindication. Indeed, in most patients the cause of the fistula will have been a previous hysterectomy. Multiple extensive prior abdominal surgeries or previous peritonitis that results in extensive bowel adhesions, and morbid obesity are relative contraindications. A previous history of pelvic radiation is also a relative contraindication at present, as successful laparoscopic repair of a postradiation vesicovaginal fistula has not been reported so far.

Informed consent

The patient must be informed about the different options of surgical repair available and their relative advantages and disadvantages. As in the case for any laparoscopic procedure, the possibility of conversion to an open procedure must be explained to the patient. The possibility of blood transfusion, infection, and injury to adjacent viscera should be explained, as well as the possibility of failure of fistula repair needing reoperation, irrespective of the technique of repair used. In addition, in the case of vesicouterine fistula, the possible need for hysterectomy must be discussed.

Preoperative preparation

Patients using oral anticoagulants like warfarin and Aspirin or other antiplatelet drugs must discontinue these 1 week prior to surgery. Patients are advised to take a clear liquid diet 1 day prior to surgery. All patients undergo mechanical bowel preparation 1 day prior to surgery using polyethylene glycol with electrolyte solution (Golytely™; Braintree Laboratories Inc, Braintree, MA, USA) or a bottle of magnesium citrate (15 g), and a cleansing enema on the morning of surgery. One dose of prophylactic antibiotics (a third-generation cephalosporin and clindamycin) is administered 30 min prior to surgery.

Operating technique of robot-assisted laparoscopic repair of a vesicovaginal fistula

The procedure is performed under general anesthesia. The da Vinci® S robot surgical system (Intuitive Surgical) is the system currently used for robot-assisted laparoscopic procedures. The patient is placed in the lithotomy position. Leg sleeves of an external intermittent pneumatic leg compression device are fixed on the legs to prevent deep vein thrombosis. The patient is prepped and draped, and a digital vaginal examination is performed under anesthesia, followed by a per speculum examination of the vagina using a Sim's speculum and anterior vaginal wall retractor. Urethrocystoscopy is then performed to study the number, location, and size of the fistula, and its proximity to the ureteral orifices and bladder neck. Double- pigtail ureteral stents or 6 F ureteral catheters are passed through the ureteral orifices bilaterally. A Foley catheter of a suitable size based on the size of the fistula is inserted from the vagina into the urinary bladder through the fistula and the balloon is inflated to plug the leak and allow bladder distention during cystoscopy. This catheter is clamped subsequently to prevent loss of pneumoperitoneum when the bladder is opened later during the surgery.

After cystoscopy, the patient is positioned in a steep (60°) Trendelenburg tilt. Pneumoperitoneum can be created using the Veress needle technique or by the open technique (Hasson's technique [14]). For the former, we prefer to insert the Veress needle at the left hypochondrium to avoid adhesions, which are often present due to previous abdominal surgeries. In cases with previous multiple intra-abdominal surgeries or with previous intra-abdominal infections, where the presence of extensive adhesions may make the insertion of the Veress needle potentially dangerous, we use the open technique for establishing pneumoperitoneum. Following creation of pneumoperitoneum, the ports are inserted as shown in Figure 88.1. A five-port transperitoneal approach is used. A 12-mm optical trocar is inserted under endoscopic vision at the umbilicus for the camera. Two 8-mm robotic ports are then placed on either side at the pararectus location over the spinal—umbilical line. Another 8-mm robotic port for the fourth arm is placed on the left side about 5 cm lateral to the left robotic 8-mm port and at least 5 cm above the iliac crest. A 5-mm port is placed on the right side 1 inch above and medial to the anterior superior iliac spine for assistance. We prefer transferring the suture through the robotic or camera port after removing the instrument,

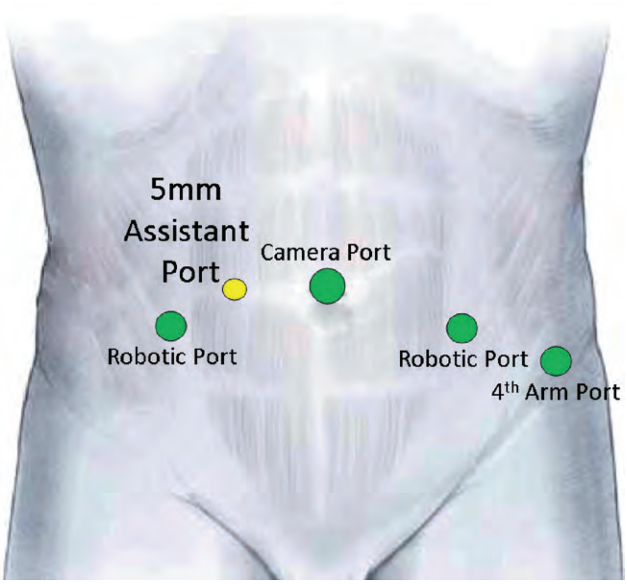

Figure 88.1 Position of ports for robot-assisted laparoscopic repair of a vesicovaginal fistula. In the case of pure laparoscopic repair, the 8-mm robotic ports are replaced with 5-mm ports.

thereby avoiding the need for another 12-mm port. The steps of the surgery are described below.

Step 1: Laparoscopic or robotic adhesiolysis

Laparoscopic adhesiolysis may be required even before the robot is docked to release the adhesions located on the anterior abdominal wall at sites where the ports are proposed to be placed. The robot is bought in from between the legs and docked with the camera and robotic ports. Adhesions encountered are carefully dissected using robotic monopolar curved scissors and Maryland bipolar forceps to expose the superior aspect of the bladder, the uterus if present, and the rectovaginal pouch. The patient-side assistant helps with the suction–irrigator and blunt-tipped grasper. In posthysterectomy cases, the small bowel loops or the sigmoid colon may be adherent to the bladder and vaginal vault, and they must be carefully dissected off the underlying bladder.

Step 2: Cystotomy

A gentle tug on the Foley catheter passing through the fistula further helps locate the approximate site of the fistula as seen from within the abdominal cavity, allowing the creation of a minimal cystotomy in the midline above the adherent area. A midline cystotomy is made using a robotic monopolar curved scissors on the posterior wall of the bladder and it is extended up to the fistulous opening, which is easily identified by the presence of the Foley catheter (Figure 88.2A). The Foley catheter is removed and if the pneumoperitoneum is leaking, then the vagina is packed with a wet sponge to prevent loss of pneumoperitoneum. The cystotomy incision is then extended around the fistula in an inverted racquet fashion. Alternatively, the Foley catheter can be pulled intra-abdominally through the cystotomy by holding its tip with a robotic ProGrasp forceps and used to retract the anterior bladder wall, splinting open the cystotomy to allow better visualization of the fistula and the stented or catheterized ureteral orifices (Figure 88.3). In the case of a vesicouterine fistula, there is no need to pack the vagina as there is no loss of pneumoperitoneum. Furthermore, no catheter is preplaced in the fistula as this is neither feasible nor required.

Step 3: Separation of the bladder and vagina

The bladder is then mobilized off the anterior aspect of the lower uterine segment or vagina. The preplaced stents or ureteral catheters provide an anatomic bearing of the ureteral orifices and help prevent or identify inadvertent injury to the ureters. The fistula is circumscribed, disconnecting the bladder from the anterior vaginal wall. It is not necessary to excise a wide rim of tissue along the edges of the fistula; trimming the edges until well-vascularized tissue is seen is good enough. The plane between the bladder and the vagina is then developed with sharp dissection for a distance of about 2 cm from the fistula to allow tension-free closure on either side. The key point in technique is slow and careful sharp dissection of the fistulous edges, because the trigone and ureteral orifices invariably lie in close proximity. Also, careful dissection helps preserve the vascularity of the tissues and thereby avoids the need for wide excision, which may hamper subsequent closure. The fistulous edges are freshened and bleeding is controlled with bipolar diathermy.

Step 4: Reconstruction of the vagina and bladder, and tissue interposition

The vagina is first closed with a continuous running stitch with 3-0 poliglecaprone (Monocryl) on a round body needle using two robotic large needle drivers (Figure 88.2B). The adequacy of closure is indirectly tested by the lack of loss of pneumoperitoneum upon removal of the vaginal pack. The bladder is reconstructed in two layers using 3-0 poliglecaprone (Monocryl) in a transverse or vertical fashion, based on the defect created after excision or refreshing of the fistulous edges and mobilization of the bladder flaps (Figure 88.2C). However, it is not always possible to perform repair in this manner, especially if the fistula is close to a ureteral orifice. In such cases, we perform a Z plasty modification with the final suture line appearing

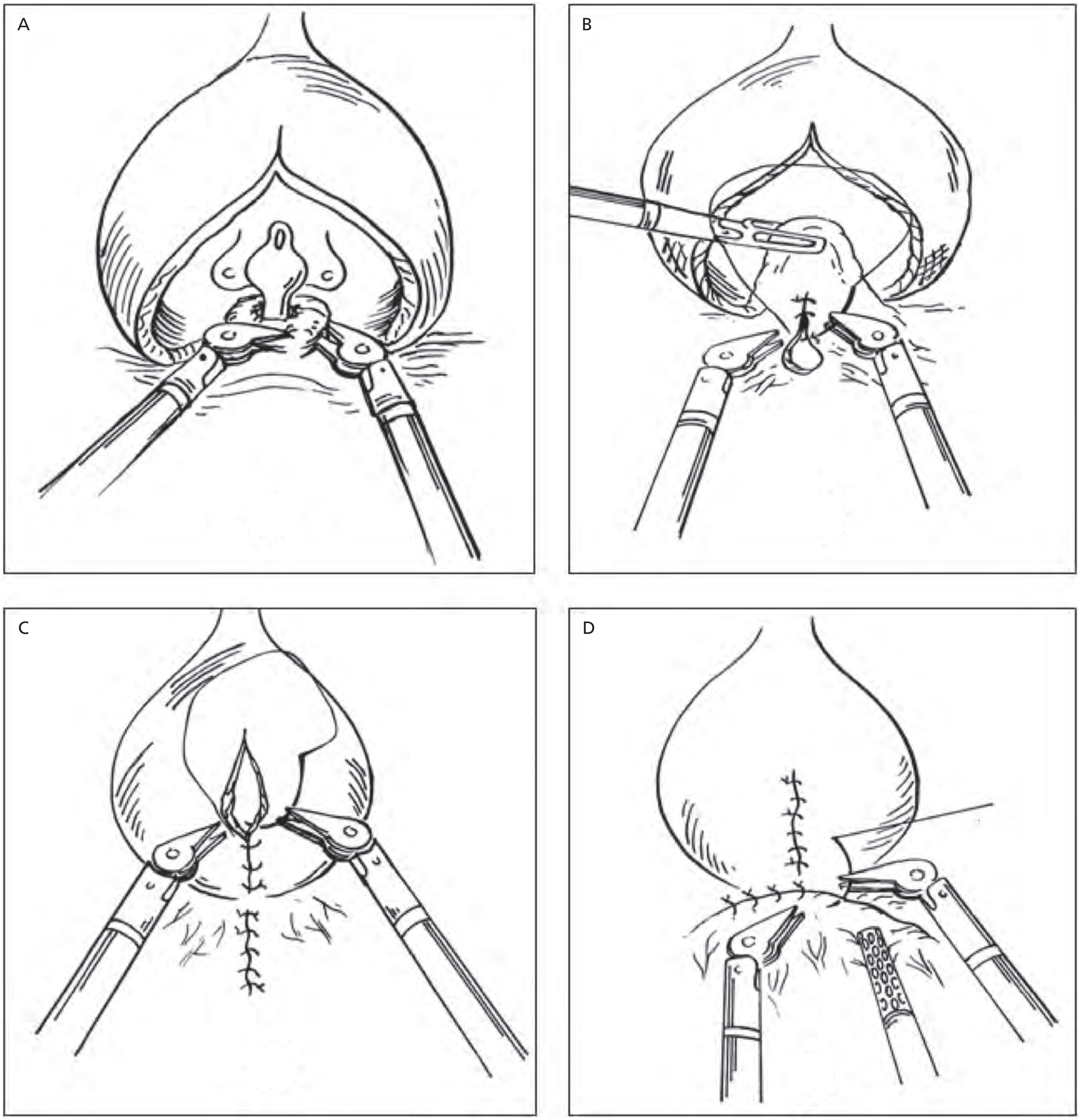

Figure 88.2 Key steps in the repair of a vesicovaginal fistula: (A) Cystotomy and dissection of the fistula using robotic monopolar curved scissors and robotic Maryland bipolar forceps. (B) Reconstruction of the vagina with 3-0 poliglecaprone on a round bodied needle. (C) Reconstruction of the urinary bladder with 3-0 poliglecaprone on a round bodied needle. (D) Interposition of omentum between the urinary bladder and vagina. All intracorporeal suturing is performed using two robotic large needle drivers.

like a Z or an inverted Y, or with a dog-ear on one side. We prefer to interrupt this running stitch by intermittently locking or knotting it to prevent any laxity of the suture line. After final closure, the bladder is moderately distended to assess the integrity of closure with sterile water or saline, which is instilled through an indwelling 18F Foley catheter inserted per urethra. Any minor leakage detected is closed with additional interrupted 3-0 polyglactin (Vicryl) sutures. A well-vascularized pedicled greater omentum is then mobilized and is interposed between the bladder and vaginal suture lines. The omentum is tacked using 3-0 poliglecaprone

(Monocryl) to the resilient vaginal wall, which provides stability, to cover the vaginal suture line (Figure 88.2D). When omentum is unavailable or it cannot be adequately mobilized, the epiploic appendices of the sigmoid colon or a peritoneal flap is used for interposition between the suture lines. A drain is then placed in the rectovaginal pouch.

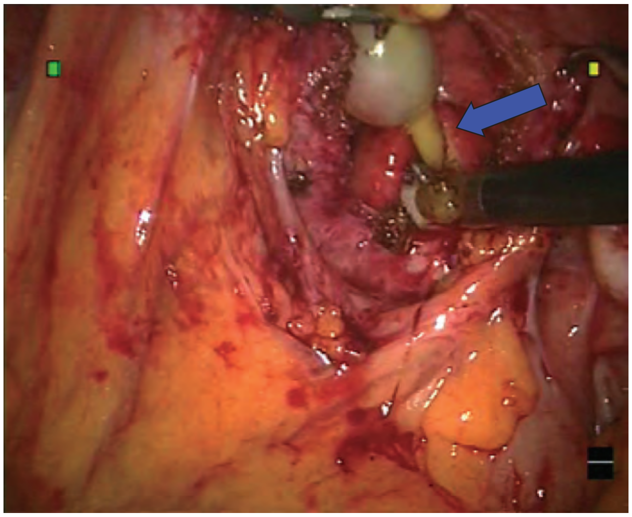

Figure 88.3 The Foley catheter passed through the fistula is pulled intra-abdominally through the cystotomy by holding its tip with grasping forceps, and is used to retract the anterior bladder wall, splinting open the cystotomy to allow better visualization of the fistula (arrow).

In the case of repair of a fistula involving the cervix, a ureteral catheter preplaced into the uterus at the beginning of surgery helps in the accurate repair of the cervix without unduly narrowing the os [15]. Excessive narrowing of the os can lead to stricture of the cervical canal and hematometra. In a vesicouterine fistula, the uterus is closed with interrupted sutures using 3-0 polyglactin on a round bodied needle. Occasionally in these cases, hysterectomy may be needed [16]. While this can be performed with robotic assistance, the detailed description of the technique is beyond the scope of this chapter.

Combined repair of vesicovaginal and ureterovaginal fistulas

We have experience in repairing complex urinary fistulas, which includes repair of vesicovaginal and ureterovaginal fistulas [17, 18][8]. In case the fistula is too close to a ureteral orifice or if there is a coexistent ureterovaginal fistula, the distal ureter is identified at the level of the bifurcation of iliac vessels and mobilized using the robotic instruments described above. The dissection must be done with care, releasing the ureter from the often dense periureteral adhesions consequent to the previous surgery or urine leak but preserving the periureteral vasculature. With robotic assistance, excision of the terminal end of the ureter and ureteroneocystostomy are performed with 5-0 poliglecaprone (Monocryl) (Figure 88.4). If the ureteral defect is longer, the anasto-

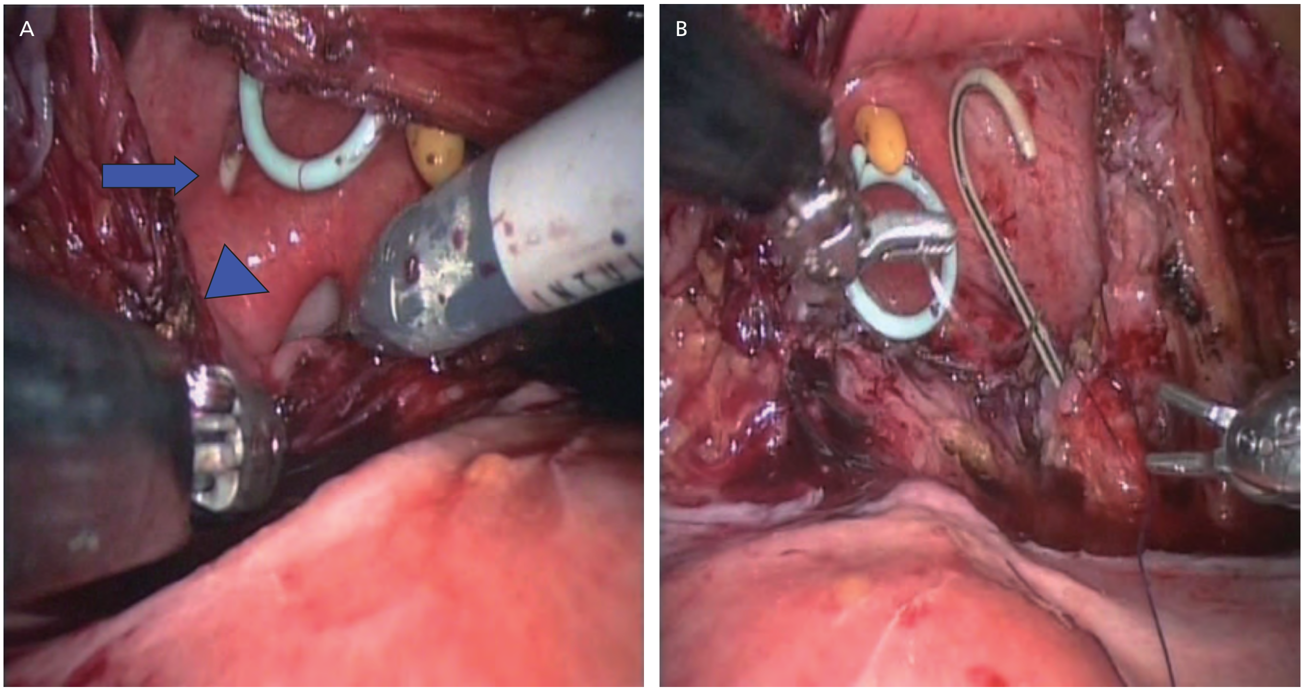

Figure 88.4 (A) Dissection of the vesicovaginal fistula and (B) right ureteral mobilization prior to reimplantation, in the same patient. The arrow shows the left ureteral orifice with the stent *in situ* and the arrow head shows the fistulous opening being circumscribed.

mosis can be facilitated by performing a psoas hitch or by the use of a Boari flap, both of which can be performed robotically [18–20] as well as with pure laparoscopic techniques [21, 22]. All these steps are carried out intracorporeally. In a known case of multiple or combined fistulas, we repair vesicovaginal and ureterovaginal fistulas simultaneously (see Video 88.1).

Step 5: Exiting the abdomen

At the end of the procedure, the pneumoperitoneum pressure is reduced to 5 mmHg to look for any bleeding, which if found is controlled with diathermy. The primary 12-mm port is closed with 1-0 Vicryl. All other ports are closed with subcuticular poliglecaprone sutures. The perurethral Foley catheter is retained at the end of surgery. We do not place a suprapubic catheter.

Operating technique of laparoscopic repair of vesicovaginal fistula

The procedure for laparoscopic repair of vesicovaginal, vesicocervical, and vesicouterine fistulas is almost identical to the above, but with several important differences: instead of 8-mm ports, two 5-mm ports are used on either side of the rectus abdominis muscle for the laparoscopic instruments [15, 23, 24]. The surgeon stands on the left side of the patient and the assistant on the right.

Postoperative care

Intravenous fluids are continued until the evening of the day of surgery, and the patient is allowed sips of water in the evening and semisolid diet next day morning. Antibiotics are continued for 24 h after surgery. Parenteral ketorolac or morphine is administered for analgesia as per need. External intermittent pneumatic compression of the calf muscles should be continued until the patient ambulates, usually on the evening of surgery or the morning of the next day. Early ambulation is desirable to reduce the risk of venous thromboembolism.

The drain is removed on the first or second postoperative day, when the drainage is less than 30 mL in 12 h. Usually the drain is removed within 24 h. The patient is discharged following removal of the drain. Occasionally, a patient may require a stay of 48 h. The indwelling catheter is removed in 10 days and a cystogram may be performed if necessary prior to removal of the catheter. We, however, consider this is not necessary in most cases. When ureteral reimplantation has been done, the ureteral stent is removed 3 weeks postoperatively in the outpatient clinic using a flexible cystoscope. The patient is advised to abstain from having sexual intercourse for 8 weeks.

Complications

Other than the complications arising due to anesthesia and immobilization, the specific complications include hematuria due to primary or reactionary hemorrhage. Blood clots can block the catheter, increasing the intravesical pressure and the strain on the suture line in the bladder. The possibility of bacteremia due to an unnoticed preoperative infection should also be borne in mind if pyrexia occurs within 24 h of surgery. Urinary tract infections acquired postoperatively can present with fever on the second or third day . The case should also be evaluated to rule out deep vein thrombosis if there is hectic fever 3 to 4 days after surgery. Appropriate antibiotics as guided by culture reports are necessary to control and curb the infection to ensure sound healing.

Few complications specific to laparoscopy have been reported in the literature on vesicovaginal fistula repair. Nevertheless, it is reasonable to expect complications similar to those described in other laparoscopic procedures. These may include injuries to the bowel, mesentery, and blood vessels, like the inferior epigastric vessels, iliac vessels, aorta or the inferior vena cava. In addition, the ureter may also be injured during separation of the bladder and the vagina, and so great caution must be exercised during this dissection.

Results of surgery

In 1996, Nezhat *et al*. described the first laparoscopic repair of vesicovaginal fistula [25]. Since then there have been 16 reports of laparoscopic vesicovaginal fistula repair. The current literature on laparoscopic repair of vesicovaginal fistula is summarized in Table 88.1 [26–37]. These show that these procedures are feasible, effective, and safe in experienced hands. The hospital stay is shortened and the estimated blood loss is in the range of 100–150 mL in most series. Operating times are typically in the range of 180–240 min, but decrease with increasing experience. The larger series show a failure rate of about 8–12%. Although these techniques were initially used predominantly for the repair of posthysterectomy vesicovaginal fistulas and postcaesarean uterovesical fistulas [38], recent series indicate that with experience these techniques can be used to treat the more complex obstetric fistulas also [27, 32]. The current literature on robot-assisted laparoscopic repair of vesicovaginal fistula is summarized in Table 88.2 [39–43]. This shows that it is feasible, safe, and carries a low morbidity. The hospital stay is short and the estimated blood loss is less than 150 mL. The operative times also show a decreasing trend in recent series as compared to older ones. Robot-assisted laparoscopic repairs have been done on both obstetric as well as gynecologic fistulas.

Table 88.1 Studies on laparoscopic repair of vesicovaginal fistula.

Study	Number of cases	Cause of fistula	Size of fistula (mm)	Average operative time (range) (min)	Average hospital stay (range) (days)	Average blood loss (range) (mL)	Remarks
Rizvi *et al*. (2010) [26]	8	Posthysterectomy; 2 previously failed	4–7	145	4	60	
Shah (2009) [27]	25	Obstetric fistulas – 7 Posthysterectomy fistulas – 16 Others – 2	NR	145	4.5	180–200	3 conversions and 3 failures
Gozen *et al*. (2009) [28]	3	Posthysterectomy	3–7	163 (141–155)	6 (4–9)	333 (250–400)	
Otsuka *et al*. (2008) [29]	7	Posthysterectomy – 6 Postureterolithotripsy – 1		280 (120–470)	7.2 (2–20)		1 inferior limb compartment syndrome 1 conversion due to time
Erdogru *et al*. (2008) [30]	1	Posthysterectomy	NR	185	3	50	Transvesical approach Used a fleece-bound sealing system
Tiong *et al*. (2007) [31]	1	Posthysterectomy	3	260	2	100	
Das Mahapatra *et al*. (2007) [32]	12	Post hysterectomy – 7 Obstetric – 5	14 (5–25)	Post hysterectomy – 140 (120–160) Obstetric – 192 (180–240)	4–7 (gynecologic) 2 weeks (obstetric)	100–150	1 failure
Nagraj *et al*. (2007) [11]	13	Post hysterectomy – 13	18 (14–31)	130 (110–160)	4.5 (3–7)	NR	1 failure; 1 conversion
Wong *et al*. (2006) [33]	2	Post hysterectomy; previous failed Latzko – 2	NR	450 and 312	2	100	
Chibber *et al*. (2005) [24]	8 (includes 2 uterovesical fistulas)	Posthysterectomy – 6 Postcaesarean uterovesical – 2	12 (8–20)	220 (190–280)	3 (intention to discharge)	NR	1 conversion
Sotelo *et al*. (2005) [34]	15	Posthysterectomy – 14	NR	170 (140–240)	3 (2–5)	NR	1 concomitant ureteric reimplant 1 nephrectomy
Ou *et al*. (2004) [35]	2	Post hysterectomy – 2	NR	NR	2, 12	NR	
Nabi *et al*. (2001) [23]	1	Post hysterectomy – 1	20	190	4	NR	Concomitant nephrectomy
Miklos *et al*. (1999) [36]	1	Post hysterectomy – 1	NR	NR	1	NR	
Von Theobald *et al*. (1998) [37]	1	NR	NR	70	8	100	
Nezhat *et al*. (1996) [25]	2	Posthysterectomy – 1 Others – 1	NR	NR	NR	NR	

NR, not reported.

Table 88.2 Studies on robot assisted laparoscopic repair of vesicovaginal fistula.

Study	Number of cases	Cause of fistula	Average operative time (range) (min)	Average hospital stay (range) (days)	Average blood loss (range) (mL)	Remarks
Melamud *et al*. (2005) [38]	1	Posthysterectomy	280	2	50	
Sundaram *et al*. (2006) [36]	5	Posthysterectomy – 4 Postmyomectomy – 1	233 (150–330)	5 (4–7)	70	Average size 3.1 cm (2–4 cm)
Schimpf *et al*. (2007) [40]	1	Posthysterectomy – 1	240	2	NR	
Sears *et al*. (2007) [41]	1	Posthysterectomy – 1	NR	NR	NR	
Hemal *et al*. (2008) [42]	7	Posthysterectomy – 3 Post caesarean section – 2 Obstetric – 1	141 (110–160)	3 (2–4)	90 (50–150)	Average size of VVF 3 cm (2–4 cm)

NR, not reported; VVF, vesicovaginal fistula.

Robot-assisted laparoscopic repairs of pure reimplantation of the ureter for posthysterectomy ureterovaginal fistulas [17], as well as repair of vesicovaginal fistula repair combined with ureteric reimplantation, have been reported (personal communication). There is as yet no report of enterocystoplasty or treating a radiation-induced fistula using these minimal access techniques. However, with increasing experience and better instrumentation, more and more complex fistulas are likely to be repaired using these minimal access techniques in the future.

Conclusions

Laparoscopic techniques with or without robotic assistance are being increasingly used for the repair of vesicovaginal fistulas. Although these minimally invasive procedures are challenging with a fairly steep learning curve, it is now established that they are safe and effective in vesicovaginal fistula repair, and have the benefits of short hospital stay, lower need for analgesics, lower blood loss, and faster convalescence. They can be performed by any urologist trained in laparoscopic/robotic surgery. While many advantages of minimal access techniques in vesicovaginal fistula repair are now established, the cost-effectiveness of these techniques will vary in different regions and merits evaluation. Robotic assistance makes intracorporeal suturing much easier, thereby facilitating reconstructive procedures like vesicovaginal fistula repair. However, the very high cost of the surgical robot has restricted the widespread adoption of this minimally invasive technique for the repair of vesicovaginal fistula.

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CHAPTER 89

Laparoscopic and Robotic Bladder Surgery

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Introduction

In the early 1990s, attempts were made by urologists to conduct extirpative and reconstructive procedures using laparoscopy. The first reported laparoscopic cystectomy was by Parra *et al*. in 1992 for pyocystitis [1] and the first laparoscopic radical cystectomy for malignancy was completed by Sanchez *et al.* in 1993 [2]. With the development of instrumentation, skill, and expertise, applications of laparoscopy have expanded to more bladder procedures, such as partial cystectomy, bladder augmentation, and appendico-vesicostomy.

The turn of the century saw a surge in laparoscopy with robotic assistance. Laparoscopy in itself has the benefit of improved vision, especially in the narrow spaces in the abdomen. The entry of robotics enhanced the benefits of laparoscopy. Three-dimensional (3D) high-definition imaging, elimination of tremors, ergonomic positioning of the surgeon, and the EndoWrist™ have redefined minimally invasive surgery, and the benefits they bring clinically translate to shorter operative times and less blood loss. On the downside, the use of the robot has escalated cost, but with continuing technologic advances, robotics is here to stay. As with conventional laparoscopy, procedures conducted robotically have also expanded to include various bladder surgeries.

As the operative techniques for conventional laparoscopy and robot-assisted laparoscopy are generally the same, the techniques covered in this chapter are thus discussed collectively.

Partial cystectomy and diverticulectomy

Indications and background

Radical cystectomy is the standard treatment for recurrent, high-grade, organ-confined, muscle-invasive bladder carcinoma [3–5]. Recognizing the debilitating effects of this procedure, bladder-preserving techniques have been proposed. An ideal candidate for partial cystectomy is a patient with a first-time recurrence of a solitary tumor located in the bladder in whom a 1–2-cm margin will be feasible and whose bladder has normal function and capacity [6]. Since local control has been questioned, adjunctive radiation and/or chemotherapy have been attempted. With limited results, it still has not been widely accepted and may therefore be utilized for a select group of patients only. It may be offered to patients with severe comorbidities and those who refuse total cystectomy with appropriate advice regarding long-term results. A concomitant pelvic lymph node dissection is also advocated in all cases of urothelial carcinoma.

For patients with urachal adenocarcinoma that involves the bladder dome, partial cystectomy is also indicated [7]. A number of studies have shown the feasibility of the minimally invasive approach for this indication (see Results below).

Diverticulectomy of the bladder is an accepted procedure as weakness in the bladder wall at these outpouchings interferes with complete voiding. Other accepted indications for bladder diverticulectomy include large

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and symptomatic diverticula associated with lithiasis, cancer, recurrent infections, and those causing ureteral reflux or obstruction [8]. Laparoscopic and robot-assisted approaches have been proven to be feasible and safe (see Results below).

Operative technique

Patient positioning

The patient is placed in the lithotomy position with all pressure points padded. Arms, legs, and chest are secured to the operating table (Figure 89.1). The hips are hyperextended and the table tilted to a low-to-steep Trendelenburg.

1. Port placement and instruments

Initial access may be via the Veress or Hasson technique. For conventional laparoscopy, a five- or six-port configuration is used, similar to laparoscopic prostatectomy (Figure 89.2A). With the use of the robot, a five- or six-port configuration is used, similar to robot-assisted

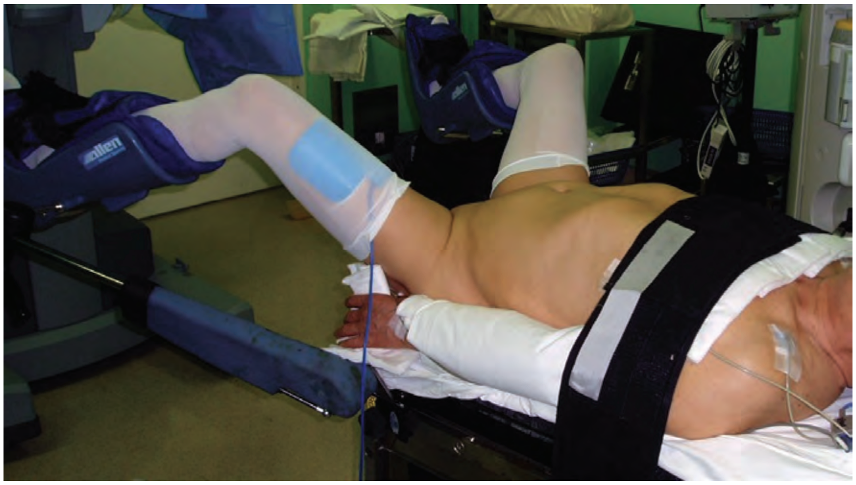

Figure 89.1 Initial patient position. Patient in lithotomy with chest, arms, hands, and legs padded and secured.

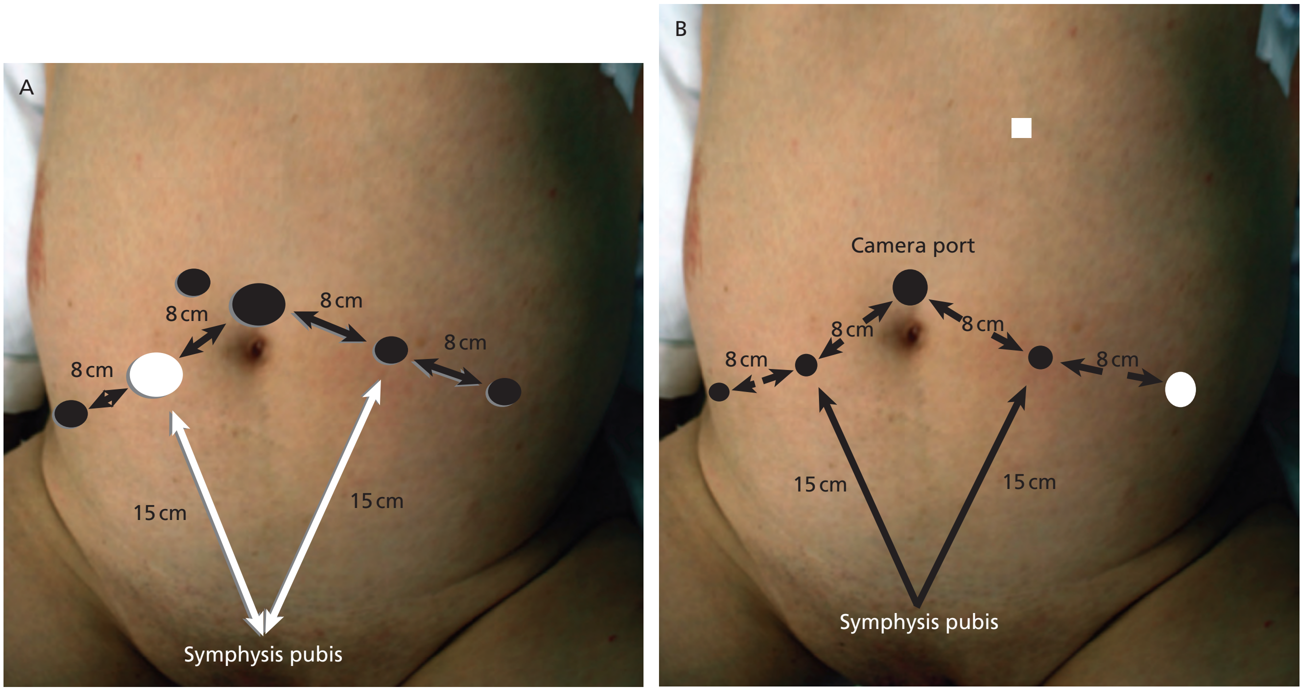

Figure 89.2 (A) General conventional laparoscopic bladder surgery port placement: A 12-mm supraumbilical camera port, three 5-mm ports, and a 12-mm working port (white circle). (B) General robotic bladder surgery port placement: a 12-mm supraumbilical camera port, three 8-mm robot ports, a 12-mm assistant port (white circle), and a 5-mm assistant port (white square).

laparoscopic prostatectomy utilizing four robot arms. (Figure 89.2B). The fourth arm may be used on the right or left depending upon the surgeon's preference. At least one assist port (12-mm trocar) should be used for entry and exit of sutures, and suctioning. The camera port is placed supraumbilical. For cases of urachal cancer, it should be placed about 3–5 cm cephalad to the umbilicus.

The conventional laparoscopy instruments are grasping forceps, monopolar scissors, ultrasonic shears or J-hook electrocautery. Robotic instruments are bipolar forceps, monopolar scissors, needle driver, and optional grasping forceps for the fourth arm.

Steps of the procedure

Partial cystectomy

Upon insertion of the laparoscope, the abdomen is inspected for any abnormal or unusual findings. Any small or large bowel adhesions to the bladder are released as necessary.

The peritoneum is incised lateral to the medial umbilical ligaments, dividing it close to the urachus and dissecting down to the pubis. For urachal cancer, resection is performed more cephalad up to the umbilicus, and should include the posterior rectus sheath.

The bladder is incised about 2 cm from the presumed site of the tumor circumferentially. The specimen is then placed in an entrapment bag for later extraction. For bladder adenocarcinoma, the resection should be wide and include the urachal remnant.

Using a 2-0 absorbable suture such as Vicryl, the bladder defect is repaired in two layers. A continuous or interrupted technique may be used, depending on the surgeon's preference, as long as a watertight repair is achieved. The bladder is then distended with 150–200 mL of saline to check for leaks.

Pelvic lymph node dissection is advocated for all cases of bladder carcinoma to adequately stage the disease. Some authors prefer to conduct the lymphadenectomy prior to releasing the bladder and cystotomy to minimize handling of local tissues after the bladder is opened [9]. The technique is the same as described below for lymph node dissection during radical cystectomy. A drain is inserted and all instruments are pulled out. The specimen is delivered through the umbilical port with enlargement if necessary. Fascia repair is done on all ports larger than 8 mm. Subcutaneous tissue and skin closure are the final procedures.

Bladder diverticulectomy

After the ports are placed, all bowel adhesions to the bladder are released. Under direct vision of the laparoscope, cystoscopy in then performed.

The diverticulum is identified. It has been proposed that a urethral catheter [10] and angiocatheter [11] are inserted into the diverticulum for distention and identification intraperitoneally. Alternatively, via cystoscopy, a Collings knife is used to circumferentially mark or resect the diverticulum with a 1-cm margin, also under direct visualization through the robot camera port in the abdomen [12].

The bladder and diverticulum are inflated. Overlying peritoneum and fat are dissected. The diverticulum is then resected at its base with a margin of about 1 cm. The specimen is placed in an entrapment bag for later extraction.

Bladder repair and finishing are as described above.

Tips and tricks

During preoperative evaluation, multiple bladder biopsies should be taken to rule out multifocal disease or presence of carcinoma *in situ*, which are contraindications to partial cystectomy.

Care should be taken during resection in close proximity to the ureters as inadvertent injury may occur. If deemed necessary, ureteral stents may be inserted to aid in identification.

As diverticula commonly occur due to chronic obstruction, relief of the antecedent obstruction should also be done, but there is no clear consensus on whether this should be done before or after the diverticulectomy. However, if the diverticulectomy is done first, an endoscopic procedure after repair is ill-advised as bladder distention may weaken the repair.

For resections of the dome of the bladder, it is safe to clip the superior vesical artery to prevent excessive bleeding during the procedure and allow adequate mobilization of the bladder.

In high-risk disease, multimodal treatment can be used, such as preoperative chemotherapy and possible radiotherapy [6].

One issue with partial cystectomy is tumor seeding once the bladder has been opened intraperitoneally. Haddad *et al.* suggested the use of preoperative irrigations of intravesical chemotherapy [13]. However, this has not been generally accepted or practiced due to limited data. Spillage of urine or fluid during or after cystotomy should be avoided. Port site metastasis is also an issue but there is little data on its occurrence.

Frozen section analysis of bladder margins may be performed to ensure adequate margins.

Postoperative care

A drain may be kept for at least 24 h to evacuate secretions due to the dissection or aid in early identification of cystorrhaphy leaks. The Foley catheter is kept indwelling for 7–10 days. A cystogram may be done to confirm a healed bladder prior to removal of the catheter.

Complications

The most probable complication is urine leakage from the bladder repair. However, with a well-conducted repair, this should not be expected. A water-tight repair can be confirmed intraoperatively by inflating the bladder with 150–200 mL of normal saline. If present though, it can usually be managed by maintaining an indwelling Foley catheter for longer than usual. Other possibilities include bleeding, infection, voiding dysfunction, and postoperative adhesions. Infection can be prevented by ensuring sterile urine, especially in patients who are chronically obstructed and have large diverticula. Bleeding is easily identified with the vision provided by the laparoscope and the majority of bleeds are controlled by the cystorrhaphy. Bladder capacity is dependent on the amount of bladder tissue resected. As with any abdominal surgery, adhesions may develop and may result in intestinal obstruction.

Results

The majority of studies on laparoscopic partial cystectomy are on nonurothelial tumors. Chan *et al*. and Wadhwa *et al*. reported on urachal adenocarcinoma [14, 15]. The study of Nerli *et al*. involved two cases of urachal adenocarcinoma and one case of transitional cell carcinoma [16]. Follow-up after 24.6 months did not reveal any recurrence. Tai *et al*. reported four cases: one bladder endometriosis, one leiomyoma, one urachal adenocarcinoma, and one urothelial carcinoma within a diverticulum [17]. The one case of urothelial carcinoma had a recurrence after 3 months at a different site, which was managed by endoscopic resection. Follow-up after 12 months did not reveal any recurrence. Marino *et al*. have reported the only study solely on transitional cell carcinoma of the bladder managed by laparoscopic partial cystectomy [9]. Of six patients histopathologically staged from pT1G3 to pT3aG3, one had local recurrence with accompanying distant metastasis to the bone and liver 9 months after partial cystectomy. They did not, however, mention which patient had the recurrence. A summary of the results of these studies is given in Table 89.1.

Robot-assisted partial cystectomy has been utilized for both benign and malignant conditions. Although data are few, results have been positive. A number of series have shown the feasibility and safety of robotic application in partial cystectomy and diverticulectomy for benign tumors, diverticulum, and endometrial infiltration into the bladder [18–21]. Tareen *et al*. reported four cases: two benign bladder masses, one inflammatory diverticulum, and one urothelial carcinoma within a diverticulum [19]. Their results showed no intraoperative complications, acceptable operative time, and neg-

Table 89.1 Results of studies of laparoscopic partial cystectomy.

Study	Number of cases	Pathology	Mean operative time (min)	Mean estimated blood loss (mL)	Mean hospital stay (days)	Complications	Mean follow-up (months)	Tumor recurrence
Mariano *et al*. 2004 [9]	6	TCCA of bladder	205	200	4	Urinary extravasation (2)	30	1 case of local and distant metastasis at 9 months
Tai *et al*. 2007 [17]	4	Various*	197.5	70	6.75	None	–	1 patient after 3 months
Nerli *et al* 2008 [16]	3	Urachal adenocarcinoma and TCC	180	<200	4	–	24.6	None
Wadhwa *et al*. 2006 [15]	3	Urachal adenocarcinoma	180	150	4	Inferior epigastric artery injury	6.5	None
Chan *et al*. 2009 [14]	1	Urachal adenocarcinoma	120	<10	NA	NA	12	None

*See text.
TCC, transitional cell carcinoma.

ligible blood loss. Myer *et al*. reported successful concomitant ureteral reimplantation for a Hutch diverticulum [20]. The first report of robot-assisted partial cystectomy for bladder cancer was by Allaparthi *et al*. [22]. In this series of three patients, results were comparable to laparoscopic series and no intraoperative complications occurred, but one patient was readmitted due to bowel obstruction. No recurrences were observed over a median follow-up of 6 months.

Results of robotic application are few and short term. As more cases are conducted, sufficient data may be presented to finally determine the benefits of robot assistance in partial cystectomy and diverticulectomy.

Pelvic lymphadenectomy

Indications

Pelvic lymphadenectomy (PLND) here is discussed in the context of bladder carcinoma as it is an integral part of radical cystectomy. Not only is it important in adequately staging the disease, but studies have also shown it to benefit survival, especially when an extended template is used, resulting to more nodal yield [23–25]. Finelli *et al*. showed that laparoscopic PLND was feasible with enhanced nodal yield [26]. It is likewise advocated in cases of partial cystectomy for urothelial carcinoma.

Operative technique

Patient positioning

The patient is secured to the operating table in lithotomy and titled to a steep Trendelenburg position.

Port placement and instruments

A five- or six-port configuration is done similar to laparoscopic partial cystectomy.

For the robot-assisted transperitoneal approach, a six-port configuration is used, similar to that for partial cystectomy. The 12-mm camera port is placed 2–3 cm cephalad from the umbilicus at the midline. Two 8-mm ports for the left and right robot arms are placed 8 cm lateral from the midline and 15 cm from the upper border of the symphysis pubis. Another 8-mm port for the fourth robot arm is placed 8 cm lateral from the right robot arm. A 12-mm assist port is placed 8 cm lateral to the second robot-arm port. Lastly, a 5-mm assist port is placed 9–10 cm from the camera port in a plane midway between the camera and left robot port. This configuration is for a right-sided fourth arm with the assistant on the patient's left. It may be modified to the reverse position according to the surgeon's preference.

The instruments used are a 0° or 30° lens, bipolar forceps, monopolar scissors, grasping forceps, laparoscopic forceps, and suction probe

Steps of the procedure

Upon entry of the laparoscope, the abdomen is inspected. Any bowel adhesions to the lower gutters of the abdomen should be released to allow the intestines to fall back into the upper abdomen. The proximal part of the dissection is carried out prior to releasing the bladder. Releasing the bladder early may reduce the working space, especially in a small pelvis. Alternatively, or in cases of large bladder tumors, the node dissection may be done after the cystectomy.

The procedure is started on the left side. The posterior peritoneum is incised lateral to the sigmoid colon. The ureter is dissected and retracted laterally, while the colon is retracted medially. The peritoneum is further dissected down to the ureterovesical junction (UVJ). This exposes the common iliac vessels which are skeletonized down to the internal iliac branch (Figure 89.3). If an extended dissection is desired, the peritoneum is incised further toward the distal segment of the descending colon. The colon can then be retracted further to expose the aortic bifurcation. Nodes in this area, including the presacral area, can thus be extracted. A similar procedure is conducted on the contralateral side. The bladder is then released as in the usual transperitoneal prostatectomy/cystectomy technique. This exposes the external iliac vessels. The vas deferens is retracted and

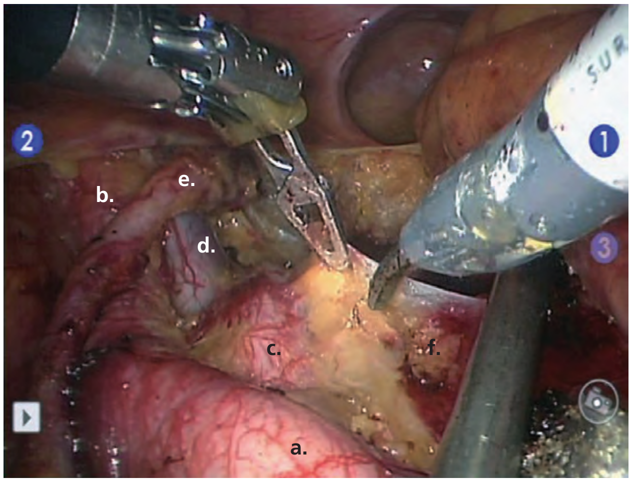

Figure 89.3 Extended pelvic lymph node dissection. After incising the peritoneum, the rectum is retracted contralaterally and the ureter is dissected revealing: a., left common iliac artery; b., left external iliac artery; c., left internal iliac artery; d., left external iliac vein; e., left ureter; and f., presacral area.

the iliac vessels are skeletonized from the anterior abdominal wall down to the iliac bifurcation. In the area of the proximal external iliac vessels, the obturator vessels can be identified and preserved. When persistent bleeding is encountered from the obturator vein, it may be sacrificed. Often, there is a perforating tributary of the obturator vein to the pelvic side wall inferolateral to the obturator nerve. Care must be taken in this area since it may also result in persistent bleeding once injured. A similar technique is conducted on the contralateral side.

Tips and tricks

Judicious use of cautery or hemostatic clips is warranted during dissection as much oozing may be experienced from small vessels. Although the amount of bleeding may be insignificant, it affects good visualization of the field.

Postoperative care

Closed suction drains are important for the drainage of secretions due to the dissection and also for cases with lymphorrhea. Aside from perioperative prophylactic administration of subcutaneous heparin, early ambulation or mobilization of the lower extremities also contributes to the prevention of thrombus formation.

Complications

As the dissection is in close proximity to blood vessels and nerves, injury to these structures is always a possibility. Preventive measures include anatomic dissection and careful use of sharp dissection and electrocautery. Minor vessels may be clipped. Injury to major vessels should be repaired. Pneumoperitoneum and manual tamponade can limit bleeding initially. An appropriate repair can subsequently be done with vascular sutures. Bowel and ureteral injuries may also occur during dissection. Immediate identification is crucial as they may lead to peritonitis, urinoma, and sepsis. If identified early, they may be repaired primarily; ureteral injuries will require a double-pigtail stent.

Another complication of lymphadenectomy is lymphocoeles. Although a transperitoneal approach may be associated with a lower incidence, it still may occur. It is still controversial whether intervention is warranted for asymptomatic lymphocoeles; however, symptomatic ones usually necessitate treatment ranging from percutaneous drainage to laparoscopic or open drainage.

Deep vein thrombosis may also occur. Preventive measures include prophylactic administration of heparin and compression devices.

Results

PLND is an integral part of radical cystectomy and is generally accepted in partial cystectomy. The current issue is the extent of dissection deemed necessary. Standard dissection includes the following borders: lateral – , genitofemoral nerve;; medial – bladder; cephalad – bifurcation of the common iliac artery; and caudal – endopelvic fascia. The current trend is to consider an extended dissection as some studies have shown survival benefit [23–25]. This appears logical as some studies have shown skip nodal metastasis [24]. In addition, the report by Capitiano *et al*. showed that analysis of 45 nodes resulted in 90% detection of nodal metastasis, whereas analysis of another 25 nodes resulted in 75% [27]. Although there are conflicting studies and randomized controlled trials are not yet available, an extended dissection is the best management option at this time from an oncologic point of view.

As minimally invasive surgeons have gained skill and confidence with continued use, conventional laparoscopic and robot-assisted approaches to PLND have proven to be feasible [26, 28] and results are comparable to those with the open technique.

Radical cystectomy

Indications and background

Radical cystectomy with PLND is still the standard treatment for muscle-invasive bladder carcinoma in the absence of metastatic disease and in some patients with refractory local symptoms in whom palliative surgical management may be necessary [29].

The minimally invasive approach for radical cystectomy is an attractive option due to the potential benefits of shorter convalescence, decreased morbidity, and improved health-related quality of life [30]. Perioperative outcomes of laparoscopic techniques generally show less blood loss and lower transfusion rates, shorter hospital stay, and earlier resumption of a regular diet. Short-term results are oncologically similar to those for an open technique, but long-term results are few.

As the procedure itself is technically difficult even with the open approach, substantial experience in laparoscopy is a prerequisite to a successful minimally invasive approach to radical cystectomy. Patient selection is also a critical factor to achieve acceptable, if not excellent, results. Organ-confined, low-volume disease is preferred as large tumors may limit the working space and wider excisions may be necessary in more aggressive disease. Multiple previous abdominal or pelvic surgeries may be considered only a relative contraindication as there have been reports of success with minimally invasive techniques in these groups of patients [31].

However, Yuh *et al.* reported that although previous lower abdominal surgery may not affect the likelihood of safe completion of robotic cystectomy, there is a higher risk for postoperative complications [32]. Obesity is likewise a relative contraindication as some report success even in these patients. Previous pelvic radiation therapy is considered by many to be a contraindication. Whether conventional or robot-assisted laparoscopy is better cannot be clearly delineated at this time. Results are few and short term, and there are no data from randomized controlled trials. At this time, the critical points for success in the minimally invasive approach to radical cystectomy are technical skill and experience, whether with conventional or robot-assisted laparoscopy, and patient selection. Which technique is better for urinary diversion will not be further discussed, but various studies have reported the feasibility of a number of approaches ranging from the typical ileal conduit to neobladders in both extracorporeal and intracorporeal access.

Operative technique

Patient preparation and position

Bowel preparation includes a mechanical and antibiotic component. Mechanical preparation may be done in the conventional 3-day format or a 1-day format with two doses of laxative (Phospho-soda®) on the day prior to surgery while the patient is on clear liquids and intravenous fluids. Nil per mouth is instituted on the evening prior to surgery. The antibiotic preparation includes 1 g of erythromycin and 500 mg of metronidazole every 8 h for three doses on the day before surgery and a third-generation cephalosporin 1 h prior to the operation.

The patient is positioned similarly to the position used for partial cystectomy and PLND.

Port placement and instruments

A transperitoneal approach is used. Port placement is similar to that described for PLND (Figure 89.2). The camera port is placed 2–3 cm caudal to the umbilicus. This set-up is also appropriate for extended pelvic node dissection and for sufficient dissection of the ureter proximally.

The instruments used are a 0° and 30° lens, bipolar forceps, monopolar scissors, grasping forceps, laparoscopic forceps, suction probe, metal and/or locking clips, and other hemostatic devices.

Steps of the procedure in the male

PLND may done before or after the bladder has been resected. We prefer to perform it initially to allow for clear isolation of the bladder's lateral pedicles during the dissection of the iliac vessels. During this time, the ureters are also dissected, which we believe saves more time, although this may be difficult when faced with a large bladder tumor.

The peritoneum is incised lateral to the sigmoid colon along the path of the common iliac vessels and down the pelvis along the ureter. The vas deferens is encountered, dissected proximally and distally, and transected. This allows for the dissection of the lateral pedicles as well as node dissection along the internal iliac chain. The ureter is dissected as far proximal as possible, preserving its blood supply, and then down to the UVJ. The ureter is clipped proximally and distally, and then transected. A segment from the proximal tissue should be cut and sent for frozen section analysis. After this dissection, the colon can be retracted towards the opposite side, giving a clear view of the aortic bifurcation down to the common iliac and its branches. Similar steps are conducted on the contralateral side.

The posterior peritoneum of the bladder in then opened and posterior dissection is performed, progressing caudally. The seminal vesicles and transected vas deferens are encountered and elevated. Posterior dissection is continued similarly to prostatectomy. The Denonvilliers' fascia is entered and dissection proceeds as close to the urethra as possible. Once posterior dissection is completed, dissection of the lateral bladder pedicles is then performed. The bladder is retracted to the contralateral side as the pedicles are dissected, clipped, and transected.

Next the bladder is released from the anterior abdominal wall. The peritoneum is incised lateral to the umbilical ligaments, the bladder dissected away from the rectus muscle, and the Retzius space developed. The peritoneum is transected at the area of the umbilicus. The endopelvic fascia is then opened and the pubo-prostatic ligaments transected. The anterior side of the prostate is cleared of all fat and the dorsal venous complex controlled with sutures or use of an endovascular stapler. The prostate is then dissected down to the urethra until it is ready for transection. In a nerve-sparing approach, dissection of the lateral prostatic fascia can be done, releasing the neurovascular bundle as conducted during prostatectomy. The dissection is continued from the prostatic apex to its base. The prostatic pedicles can then be controlled with the nerves safely out of the away. The urethra is clipped distal to the prostate to prevent spillage and subsequently transected. The specimen is placed in an entrapment bag. Lymph node dissection can now be done if not performed initially.

Tips and tricks

If nerve sparing is desired, care must be taken during dissection of the prostatic pedicles so as not to inadvertently transect the neurovascular bundle. This may also occur during dissection lateral to the seminal vesicles.

Timing of the lymph node dissection is generally up to the surgeon's preference. An exception is when a large bladder tumor is to be resected as it may be safer to do this once the bladder is removed, due to the compromised working space.

The authors prefer the 0° lens during posterior dissection to facilitate visualization as caudal as the prostate–urethral junction. A 30° lens may be used for the other parts of the procedure.

Steps of the procedure in the female (anterior pelvic exenteration)

The infundibulopelvic ligament is identified superolateral to the ovaries. The overlying peritoneum is entered and the ovarian pedicles identified, dissected, clipped, and transected. The peritoneal incision is extended along the broad ligament toward the uterus and bladder. The round and cardinal ligaments are seen during this dissection, and are clipped and transected.

The ureters are then dissected as for the male patient. Partial node dissection is also an option at this time. The uterus is then retracted posteriorly while the bladder is maintained anterior. Peritoneum between these organs is incised and this space developed down to the cervix. The anterior vaginal wall is entered and transected on both sides, including the anterior third of the vagina in the specimen.

Lateral pedicles of the bladder are then controlled as described for the male patient. After this, the bladder is released and the retropubic space is developed. The endopelvic fascia is also opened. The dorsal venous complex is controlled and the urethra dissected to complete the urethrectomy. The specimen can then be delivered through the introitus. If orthotopic diversion is desired, the endopelvic fasica may be kept intact and the bladder transected precisely at the bladder neck. The Foley catheter is left in place, clipped, and transected to prevent spillage. The specimen is then placed in an entrapment bag.

The uterus is elevated and the transection just distal to the cervix is continued circumferentially, completing the hysterectomy. The specimen can again be delivered through the introitus or placed in an entrapment bag. The vagina is then reconstructed using a continuous interlocking stitch. If PLND has not been done initially, it may be done at this time.

Tips and tricks

Pneumoperitoneum may decrease from the time the vaginal wall is entered. However, the pelvis and the fixed placement of the robot trocars maintain an adequate working space. For this reason also, adequate hemostasis should be instituted prior to opening the vaginal wall.

There have been reports of prevention of loss of pneumoperitoneum with balloon devices, a sponge stick in the vagina, and temporarily suturing the vulva shut. Sears *et al.* reported the use of an anastomotic sizer modified with an occlusion balloon to preserve pneumoperitoneum [33], while Sabella *et al*. reported using a uterine manipulator with an adapted inflatable balloon inserted vaginally [34]. These techniques may be adopted during cystectomy to prevent or at least minimize gas loss.

Urinary diversion

Ileal conduit: extracorporeal technique

A 5–7-cm periumibilical incision is made, including the camera port site. In the male, the specimen is delivered. The dissected ureters are then identified and ureteral stents are placed. The left ureter is passed beneath the sigmoid colon to the right hemi-abdomen. The ileocecal valve is identified and a 20-cm segment of ileum is selected 20 cm from the valve. The ileal segment is harvested with its blood supply and the bowel continuity is restored. The proximal end of the conduit is closed in two layers. Two incisions on the antimesenteric border of the conduit are made about 2 cm apart. The stents are placed through these incisions and the ureteroileal anastomosis done with Vicryl 4-0. The ileostomy may be done on the port site of the right pararectus trocar.

Ileal conduit: intracorporeal technique

In the male, a 5-cm periumbilical incision is made, excluding the camera port site, to deliver the specimen. The abdomen is then closed and pneumoperitoneum reinstituted. A 20-cm long ileal segment is selected 20 cm from the ileocecal valve. The segment is isolated using a 60-mm endoscopic linear stapler. The bowel continuity is restored by a side-to-side anastomosis using a 60-mm endoscopic linear stapler. The ureteroileal anastomosis is performed with Vicryl 4-0, with stents inserted through the conduit into the ureters. The conduit is then pulled through the abdominal wall and anchored.

Orthotopic neobladder: intracorporeal technique

This technique may be conducted as described by Schumacher *et al*. [35]. A 50-cm segment of ileum is harvested. Once isolated, it is detubularized except for the 10-cm proximal isoperistaltic Studer afferent segment. Bowel continuity is restored as described above. The urethra neobladder anastomosis is done first. A Van Velthoven technique is utilized, anastomosing the urethra at 10 cm from the distal end of the detubularized ileum with 10–12 stitches. After completing the anastomosis, the posterior of the Studer reservoir is closed using 3-0 synthetic absorbable suture. Half of the anterior part is then sutured. The ureters are then anastomosed to the proximal afferent segment using a Wallace technique. The remaining half of the anterior is then closed.

Orthotopic neobladder: extracorporeal technique

After the specimen is extracted via a 5–6-cm incision midway between the umbilicus and the symphysis pubis, the neobladder is constructed extracorporeally. A technique similar to open surgery may be used to create the neobladder: W pouch, double chimney, T pouch. Once completed, the neobladder is placed in the pelvis and a catheter inserted through the urethra into the neobladder. The abdomen is closed. Anastomosis can be done laparoscopically with or without robotic assistance. Two 3-0 synthetic absorbable monofilament sutures with an SH needle of about 15 cm in length are tied together at the ends. The anastomosis is conducted using a technique similar to the urethravesical anastomosis during laparoscopic or robot-assisted radical prostatectomy.

Tips and Tricks

After the conduit is constructed and the ureteroileal anastomosis completed, saline may be infused in the conduit to verify for leaks.

We advocate minimum but water-tight suturing in the ureteroileal anastomosis to prevent scarring and subsequent stricture formation.

The ureters should be checked for twisting and no tension should be present.

Complications

Radical cystectomy is one of the most extensive surgeries in urology. Hence, it is fraught with many possible complications. These include bleeding as the bladder is highly vascularized. The pelvic anatomy is likewise comprised of a host of blood vessels and nerve structures which could inadvertently be injured. Deep vein thrombosis is also a possibility due to the relatively long operative time and period of immobilization, as well as the risk associated with node dissection. However, preventive measures such as compression devices and perioperative heparin may be utilized. Bowel injury may also occur: rectal injury during posterior dissection, inadvertent injury to bowel falling into the operating field, and during harvest and construction of the urinary diversion. Failure to close the mesentery of harvested bowel segments may also lead to internal herniation. Urine leaks may also occur in inadequately closed urinary diversions.

Results

Worldwide experience in radical cystectomy has been increasing, with the total number of reported surgeries now amounting to more than 700 [36].

Laparoscopic cystectomy was compared to open radical cystectomy by Ha *et al*. in a nonrandomized retrospective study [37]. Comparing 34 cases of open to 36 cases of laparoscopic radical cystectomy, they found a longer operative time in the laparoscopy group, although this was not statistically different. On the other hand, estimated blood loss, transfusion rate, analgesic requirement, postoperative hospital stay, and required volume of infused fluid were less in the laparoscopy group. In another study by Porpiglia *et al*. comparing 22 open with 20 laparoscopic cystectomies, they found decreased postoperative narcotic requirement and shorter time to oral diet in the latter [38].

Table 89.2 shows selected studies on laparoscopic and robot-assisted radical cystectomy. Perioperative outcomes appear to be similar between the two techniques. Robotic application is relatively new and long-term outcomes are not yet available.

In comparing the minimally invasive approach to the current standard open radical cystectomy, oncologic outcomes and complication rates are of prime importance. The feasibility and safety of the procedure have been clearly established by a multitude of reports (Table 89.2). However, a more objective measure of the worth of a minimally invasive approach is based on oncologic principles. In an analysis of the largest laparoscopic series, Stephenson *et al*. reported a 0–7% positive margin rate, similar to those shown in Table 89.2 [48]. Herr *et al*. determined better survival rates in patients in whom more than 14 lymph nodes were extracted [49]. The studies in Table 89.2 show lymph node yield around this number also. In terms of survival rates, Hemal *et al*., who had the longest follow-up period at 38 months, observed a 73% disease-free survival rate [40]. Deger *et al*. noted a survival rate of 75% at a median follow-up of 33 months [50]. Cathelineau *et al.* reported the largest series at 84 cases, although 40 of these were prostate sparing. The survival rate was 83% at a mean follow-up of 18 months [41]. These laparoscopic cystectomy results equal those of the standard open technique. On the other hand, long-term results of robot-assisted radical cystectomy are still immature.

Table 89.2 Results of studies on laparoscopic and robot-assisted radical cystectomy.

	Laparoscopic radical cystectomy					Robot-assisted radical cystectomy				
Study	Haber and Gill [39]	Hemal *et al.* [40]	Cathelineau *et al.* [41]	Ha *et al.* [37]	Huang *et al.* [42]	Pruthi *et al.* [43]	Hemal *et al.* [44]	Menon *et al.* [45]	Wang *et al.* [46]	Murphy *et al.* [47]
Year of study	2007	2008	2005	2010	2008	2008	2004	2003	2008	2008
Number of patients	37	48	84	36	85	50 (40 male, 10 female)	23 (20 male, 3 female)	14	32	23
Mean operative time (min)	384	306	258	427.8	320	306	Cystectomy 140 Urinary diversion 150	Cystectomy 140 Ileal conduit 260 Neobladder 308	390	397
Mean estimated blood loss (mL)	378	456	550	420	280	271	200	150	400	278
Mean hospital stay (days)	–	10.2	12	10.9	14	–	4–5	–	5	12
Positive surgical margins	2 patients	1 urethal margin	–	0	0	–	0	0	2 patients	0
Complications	Major 11% Minor 14%	Rectal injury (2), vein injury (1), open conversion (1)	8%	–	14.1%	Bladder perforation (1), stomal hernia (2), ureteral obstruction (1)	–	1 patient re-explored for bleeding	–	–
Mean number of lymph nodes removed	14	14	–	14.4	–	19	3-27	4-27	17	16
Mean follow-up (months)	31	38	18	22	21.3	13	–	–	–	17 months
Recurrence	No local or port site but positive metastasis in 5.4%	35 patients without evidence of disease	Local, 5 patients Metastatic disease, 8 patients	Local, 0 Distant, 7	Local, 3 Distant, 5 Trocar, 1	7 patients	–	–	–	91% disease free at 17 months
Type of urinary diversion	18 ileal conduit 19 neobladder	Ileal conduit	33 ileal conduit 51 orthotopic neobladder	Ileal conduit Orthotopic	Neobladder	29 ileal conduit 21 neobladder		3 ileal conduit 14 neobladder	17 ileal conduit 12 neobladder 3 Indiana pouch	19 ileal conduit 4 neobladder
Intracorporeal/ extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal	Extracorporeal

Overall complication rates were noted to be higher in the intracorporeally performed urinary diversion compared to that performed extracorporeally (70% vs 22%) [51]. A significant difference in major complications requiring reoperation was also noted by Haber *et al.* between pure laparoscopic and laparoscopy-assisted urinary diversion (29% vs 11%) [52]. Some of these complications were related to the longer operative time of a completely intracorporeal approach. As Menon *et al.* showed that an extracorporeal approach to urinary diversion resulted to shorter operative times [45, 53], it seems logical to assume that this approach will result in fewer complications.

In a strict sense, comparing the results of studies using minimally invasive techniques with the standard open technique is inappropriate, since consideration should be given to the variety of techniques, patient selection, surgeon experience, and other sources of variance. However, it would also be unwise to neglect these results in the absence of properly done randomized controlled trials. The results are overwhelmingly encouraging despite the relative youth of the approach. The theoretical benefits of pneumoperitoneum, magnified vision, 3D in robotics, smaller incisions, and precise, controlled movements cannot be denied. In the coming years, these approaches may be generally accepted. However, technical skill and experience in minimally invasive surgery should also be emphasized in an extensive surgery such as radical cystectomy.

Augmentation cystoplasty

Indications

Bladder augmentation is indicated in patients with symptomatic, diminished bladder capacity and compliance in whom conservative treatment has failed. Contraindications include poorly functioning kidneys, renal tubular acidosis, liver failure, inflammatory bowel disease, short gut syndrome, and inability to perform intermittent catheterization reliably [54].

Operative technqiue

The patient is placed on a bowel preparation as described in the previous section. Port placement is similar to that for laparoscopic or robot-assisted laparoscopic cystectomy.

Steps of the procedure

A 20-cm ileal segment is harvested 20 cm from the ileocecal junction. Blood supply should be carefully preserved. The bowel continuity is then restored via endoscopic linear staplers or intracorporeal suturing. The 20-cm harvested segment is detubularized in its antimesenteric border. It is folded into a U-shape and the medial borders sutured with absorbable sutures in an interrupted fashion. The bladder is then filled with 150–200 mL of saline through the Foley catheter. The bladder dome is opened in the mid-sagittal and mid-coronal planes. The fashioned U-shaped segment is then anastomosed to the bladder with interrupted absorbable sutures. The bladder is again inflated to check for leaks in the anastomosis and reinforced accordingly. A drain is then placed in the pelvis.

Tips and tricks

Ureteral stents may be placed to help with identification during cystostomy and to prevent inadvertent injury.

The mesentery or blood supply of the harvested ileal segment should be of adequate length to reach the pelvis without tension.

Suture length may facilitate anastomosis. Elliot *et al.* in their laparoscopy study suggested 5–6 inches for interrupted suturing and 9 inches for continuous suturing [55]. Anastomosis can be tested by inflating the bladder with 100–150 mL of saline.

Complications

Associated complications include leakage, small bowel obstruction, metabolic and nutritional abnormalities, bladder calculi, and risk of malignancy relative to the bowel segment utilized for augmentation [56].

Results

Gill *et al*. described the first clinical experience on laparoscopic bladder augmentation [57]. They presented three patients with neurogenic bladder and augmentation done using the ileum, sigmoid, and cecum, respectively. Mean operative time was 6.76 h, estimated blood loss 150 mL, and hospital stay 5.33 days. A study by Rackley *et al.* on 12 patients also with neurogenic bladder reported a mean operative time of 7 h, estimated blood loss of 175 mL, and hospital stay of 5.7 days [58].

With robotic assistance, the study by Passerotti *et al*. described their technique utilizing the ileum in a swine model [59]. The first clinical description of an augmentation technique was presented by Al-Othman *et al*. [60]: operative time was 8 h and the patient was discharged on the fourth postoperative day.

Although these studies show the expansion of minimally invasive surgery to bladder augmentation, experience is still very minimal and requires high proficiency and technical capability in laparoscopy. Operative times are observably longer compared to open techniques.

Appendico-vesicostomy: Mitrofanoff procedure

Indications and background

Appendico-vesicostomy is the most widely used and reliable means of catheterizing the bladder through a channel when the urethra is not suitable [61]. It was originally described in 1980 in the management of neurogenic bladder [62]. Its continued use is due to its proven durability and few associated complications, as reported by the long-term analysis of Liard *et al*. [63].

As interest in minimally invasive surgery increased and experience in various procedures progressed, attempts at a laparoscopic and robot-assisted approach have been tried. Initial reports on the laparoscopic approach involved dissection of the bowel and harvest of the appendix, followed by an open reconstruction or the use of extracorporeal knots [64–67]. In 2004, the totally laparoscopic approach was reported by Hsu *et al*. and Casale *et al* [68, 69]. The use of robotic assistance was first presented by Pedraza *et al*. [70], followed by a few case reports and case series [71–73].

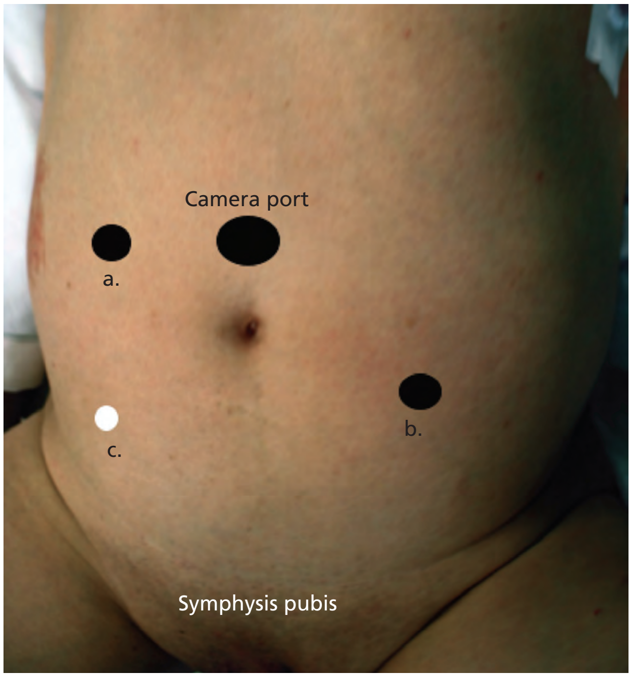

Figure 89.4 Port placement for appendico-vesicostomy. The camera port is placed more cephalic to the umbilicus. For conventional laparoscopy, a. is a 10-mm working port, b. is a 5-mm port, and c. is a 5-mm port, which is also used for the stoma. For robot-assisted laparoscopy, a. and b. are 8-mm robot ports, while c. is a 5-mm assistant port.

Operative technique

The patient is placed on a bowel preparation as described for radical cystectomy.

The adult patient is placed in a lithotomy position with the hips hyperextended and the table in a moderate Trendelenburg. Children are placed in a “frog legs” position. Port placement is described in Figure 89.4 for conventional laparoscopy and robot-assisted laparoscopy.

Steps of the procedure

The appendix is identified near the ileocecal junction. It is then dissected with the blood supply preserved. The appendix is then transected at its base with the cecal defect closed in two layers. A 8–10F feeding tube for pediatric and 14–16F for adults is inserted through the lumen of the appendix to confirm its patency. The peritoneum is incised over the anterior of the bladder. Using a technique similar to the Barry extravesical ureteroneocystostomy, two parallel incisions of diameter approximately equal to that of the appendix are made on the bladder without entering the mucosa. A submucosal tunnel is developed between the incisions, after which the mucosa on the distal incision is entered. The appendix is brought out through one incision through the submucosal tunnel, and sutured full thickness to the bladder mucosa at the 9, 3, and 6 o’clock positions. A horizontal mattress suture fixes and advances the appendix to the anterior bladder wall. The anastomosis is tested for leaks and ease of catheterization. The appendix is then externalized through the right lower quadrant trocar. Pneumoperitoneum is evacuated and the appendix stump sutured to the skin. A 10F or 16F silicone catheter is passed through the stump and into the bladder. A drain may or may not be left in the abdomen.

Tips and tricks

Mobilization from the cecum to the ascending colon along the line of Toldt may facilitate mobilization of the appendix with its blood supply towards the bladder and abdominal wall. There should be no tension in bringing the appendix to the skin.

The lumen of the appendix should be checked to ensure patency and adequate caliber.

A 5 : 1 ratio of tunnel length to appendix diameter may be used for the continence mechanism.

Complications

Postoperative complications associated with appendico-vesicostomy include infection, upper tract deterioration, stone formation, and most commonly stomal stenosis [61, 74].

Results

In two totally intracorporeal laparoscopic case reports, appendico-vesicostomy was done for pediatric patients with neurogenic bladder [62, 63]. Operative time was 198 and 360 min, discharge was on the third and seventh postoperative day, and follow-up after 8 and 9 months did not reveal any problems. Blood loss was mentioned in only one of the reports at 100 mL.

Case series on robot-assisted laparoscopic appendico-vesicostomy were reported by Storm *et al*. and Nguyen *et al.* [72, 73]. The first with three patients was published in 2007, and the second with 10 patients in 2009.: mean operative times were 301 and 323 min, estimated blood loss 50 and 48.4 mL, and hospital stay 3 and 5 days, respectively. There was one conversion due to an inadequate appendix in the second study.

These studies prove the feasibility and safety of laparoscopic and robot-assisted approaches to appendico-vesicostomy. Most of the studies, however, were conducted in the pediatric population. In the reports mentioned, there was only one adult case, a 45-year-old patient. Operative times in these studies are longer than with the open approach, although blood loss and hospital stay appear to be less. The benefit of minimally invasive techniques for this procedure still has to be proven conclusively.

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CHAPTER 90

Laparoscopic Radical Prostatectomy

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Introduction

In the USA more than 70% of radical prostatectomies are robot assisted using the da Vinci device (Intuitive Surgical, Sunnyvale, CA, USA). In Europe, there is skepticism concerning the ongoing spread of robotic systems, based on unfavorable experiences in orthopedics and cost pressures [1]. In Germany and Italy, 25% of radical prostatectomies are performed by laparoscopy (LRP). Advantages of this approach include reducing the access trauma, less pain and bleeding, and lower transfusion rates [2, 3]. Furthermore, all robot-assisted techniques are based on laparoscopy.

Historical background

In 1992, Schuessler attempted the first LRP [4]. However, his technique did not provide any advantages over retropubic radical prostatectomy (RRP) [5]. In 1995, Raboy *et al.* published a case of extraperitoneal LRP [6]. Gaston (personal communication) pioneered LRP in 1997, followed by Guillonneau, Vallancien and Abbou, who popularized the transabdominal access to seminal vesicles [7–10]. In 1999, Rassweiler *et al.* developed a retrograde technique similar to RRP [11, 12]. In the following years, several groups revisited the French technique [13–16], and in 2000, Bollens *et al*. revisited the extraperitoneal approach [17].

In 2002, a survey in Germany and Switzerland revealed that 15% of departments performed LRP, but only 5% did more than 15 cases per year [18]. In 2004, 19.2% of German departments were offering LRP [19]. In 2006, a multicenter study including 5800 patients treated by 50 surgeons was published [20]. In the USA, Gill was one of the few establishing a program of laparoscopic pelvic surgery [21, 22]. Menon initiated the change when hiring Vallancien and Guillonneau to establish LRP at his institution [23]. Perhaps more importantly, he invested in the da Vinci system and managed to perfect robot-assisted laparoscopic prostatectomy (RALP).

Indications and contraindications

Indications include men with localized prostate carcinoma and a life-expectancy of greater than 10 years [24]. All patients with stage less than T3, Gleason score less than 8, and prostate-specific antigen (PSA) less than 10 ng/mL are candidates for nerve preservation. Those with suspected extracapsular invasion (T3) or perineural invasion in core biopsies should not undergo nerve-sparing surgery (Table 90.1).

Previous transurethral resection of the prostate, abdominal or pelvic surgery, laparoscopic hernia repair, pelvic irradiation, and gross obesity can add to surgery complexity, and such patients should be approached only after considerable experience [25, 26]. Absolute contraindications are abdominal wall infection, generalized peritonitis, bowel obstruction, and uncorrected coagulopathy.

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Anatomy of the prostate

Walsh *et al.* described three layers covering the anterolateral surface of the prostate: the prostatic fascia overlying the prostatic capsule and the levator fascia [27, 28], which fuse laterally to form the lateral pelvic fascia covered by the endopelvic fascia branching off the transversalis fascia. The Denonvilliers' fascia and prostatic capsule are posterior (Figure 90.1). The neurovascular bundles (NVBs) run along the posterolateral part of the prostate between the levator and prostatic fascia, and contain branches from the inferior vesical arteries running medial to the cavernosal nerve branches originating from the pelvic plexus. These vessels enter the capsule through the prostatic fascia. The nerves initially form a group about 12 mm wide and converge at the prostate level with a width of around 6 mm at the 5 and 7 o'clock position lateral to the urethra.

Table 90.1 Criteria for nerve sparing.

Clinical stage	
T1	When PSA is relatively low and the number of positive biopsies or the extent of biopsy involvement is limited
T2a	A contralateral nerve-sparing procedure can be proposed
T2b	A nerve-sparing attempt can result in positive surgical margins and give rise to local failure

Operative techniques

Four approaches have been described: (1) transperitoneal descending with initial dissection of the seminal vesicles [8]; (2) transperitoneal ascending [12]; (3) extraperitoneal descending [29, 30]; and (4) extraperitoneal ascending [31].

Patient positioning and trocar arrangement

The patient lies in a deflected supine position, with both arms parallel to the body with adducted legs (Figure 90.2A). A rectal balloon catheter is inflated with 40–60 mL of air. The operating table is placed in a 15–20° Trendelenburg. A 16F Foley catheter is inserted. Alternatively, a lithotomy position can be used (Figure 90.2B). Some authors prefer an incline of up to 30–40° [7, 32]. A semi-lunar or W-shaped arrangement of 5- and 10-mm trocars is recommended (Figure 90.3).

Access to the prostate

Transperitoneal access is accomplished with a Veress needle (maximum pressure 15 mmHg). The peritoneum is incised over both seminal vesicles and the vas deferens are exposed and divided. Thereafter, the space of

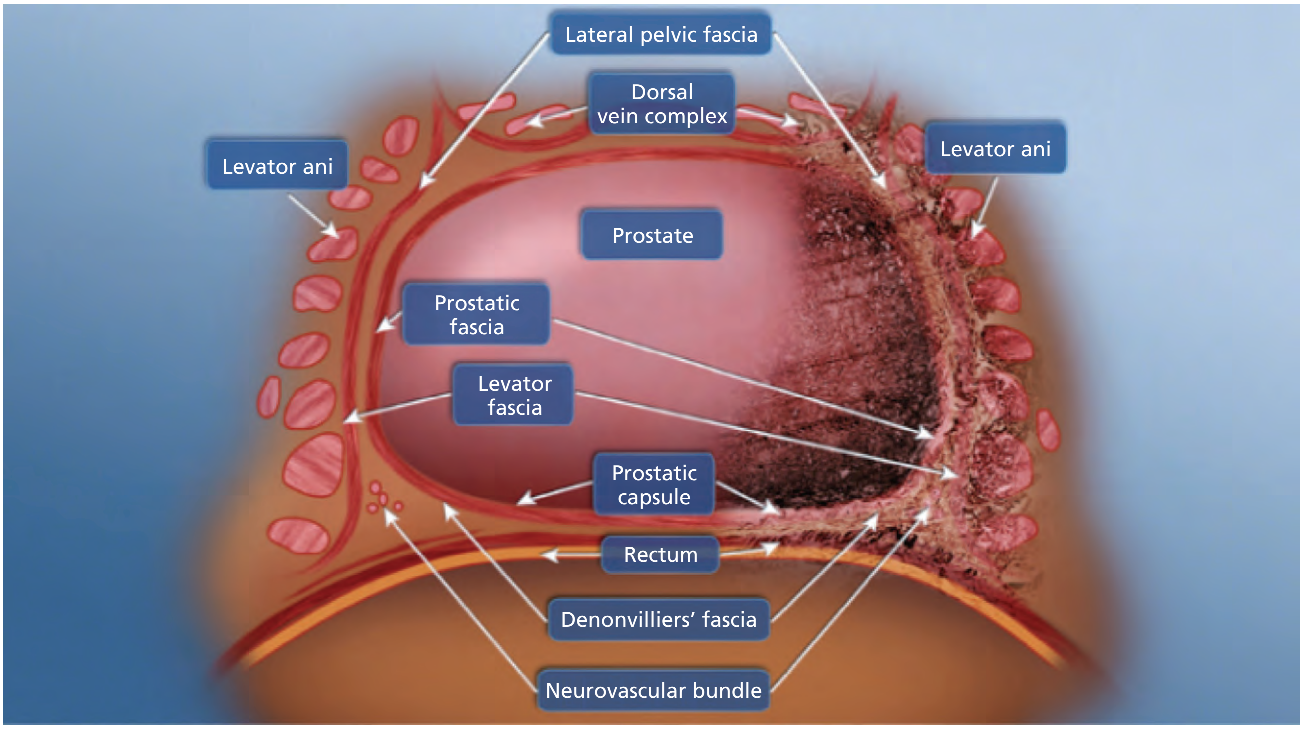


Figure 90.1 Fascial anatomy of the prostate according to Walsh *et al.* [27].

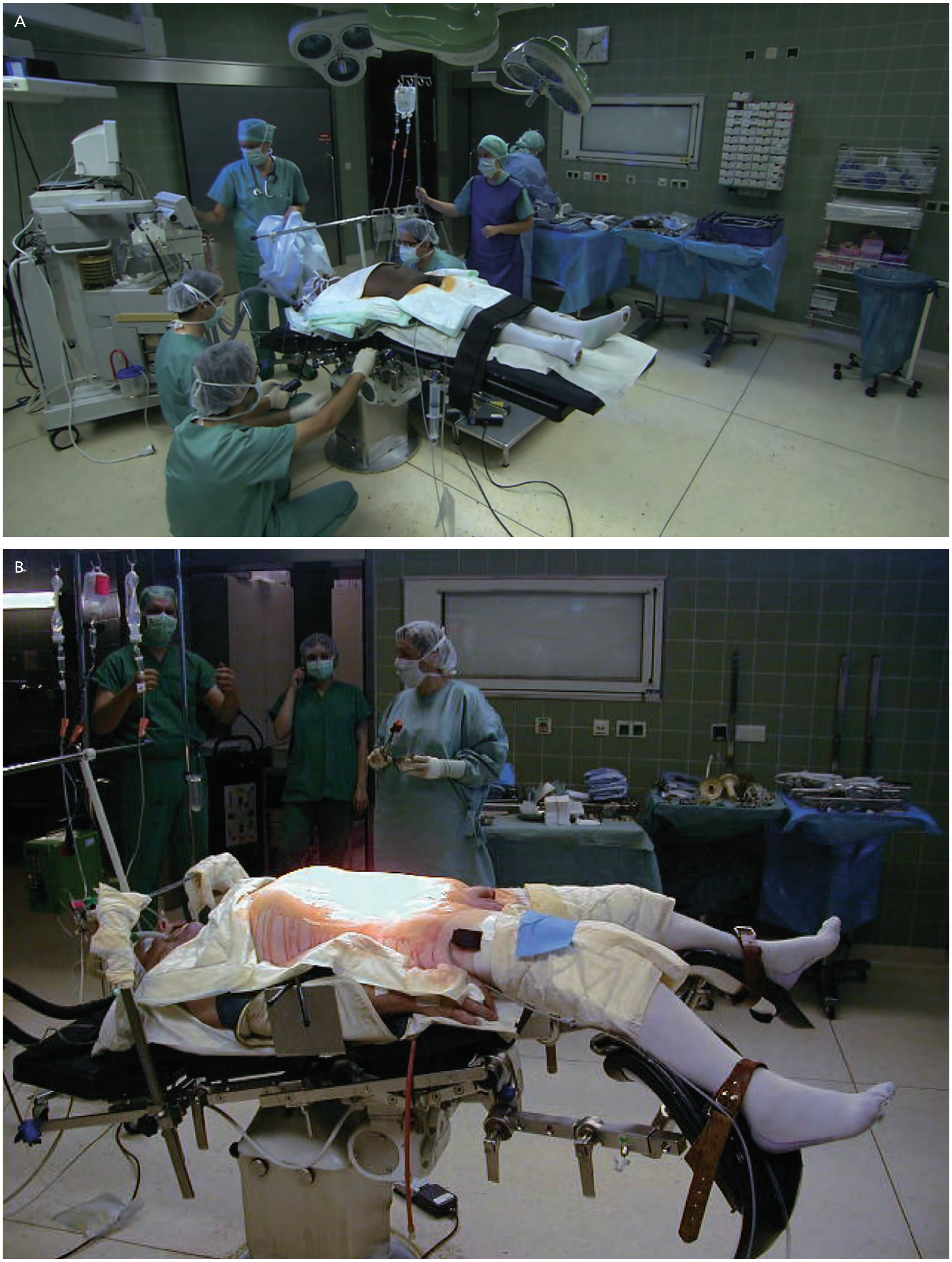


Figure 90.2 Positioning of the patient for laparoscopic radical prostatectomy. (A) Classic supine with adducted legs and 15–20° Trendelenburg (Heilbronn technique) . (B) Lithotomy position.

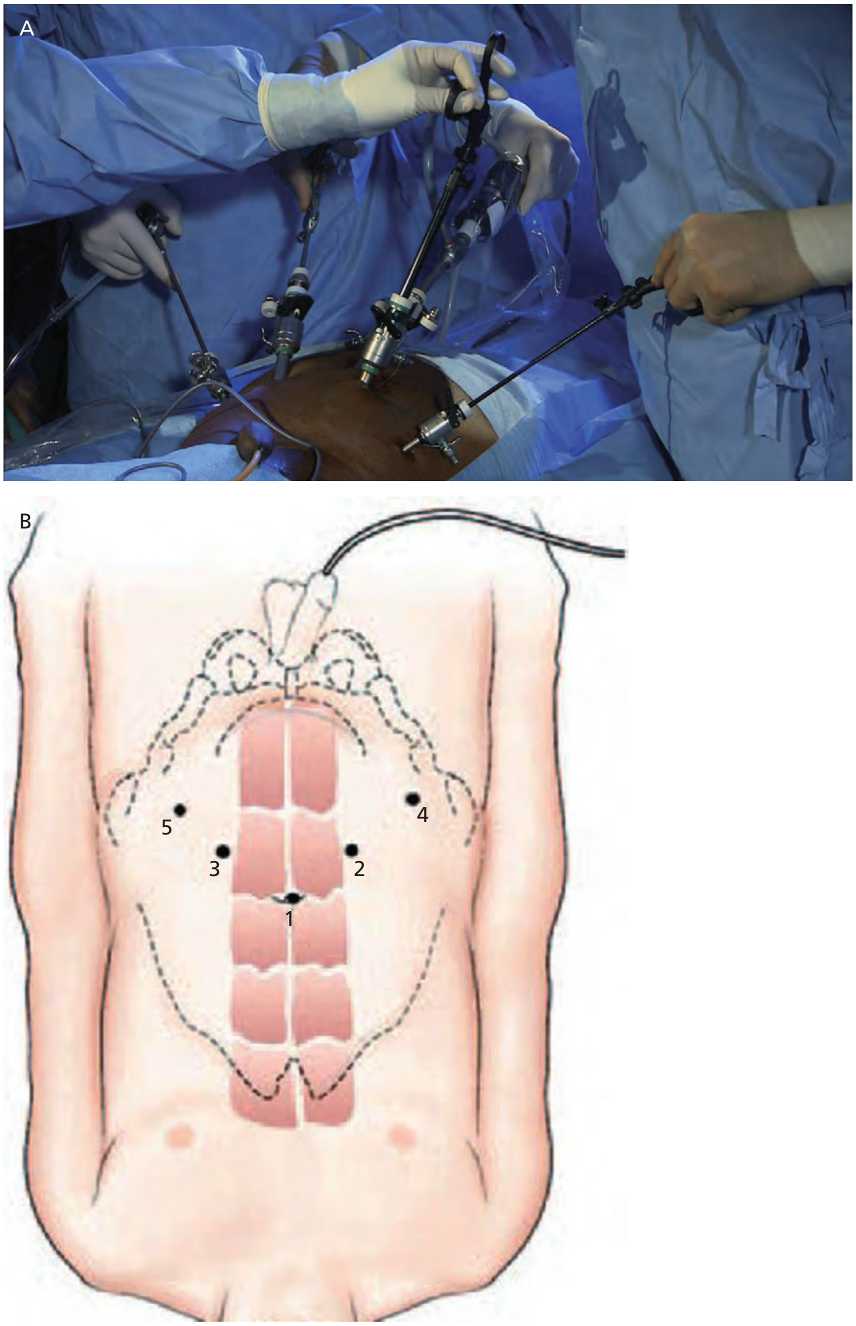


Figure 90.3 Trocar arrangement. (A) W-shape arrangement (Heilbronn technique). (B) Semilunar arrangement according to Ukimura *et al.* [22], reproduced with permission.

Retzius is developed by transection of the urachus after filling the bladder with 200 mL of saline.

Extraperitoneal access uses a periumbilical incision followed by extraperitoneal blunt dissection of the space of Retzius (balloon trocar; Figure 90.4). The other ports are placed after establishing the pneumo-extraperitoneum (maximum 12 mmHg).

Extraperitoneal versus transperitoneal approach (Table 90.2)

Transferability of the transperitoneal access was demonstrated [14, 31, 33, 34]; however, the extraperitoneal descending technique is easier to learn, as reflected in the shorter operating times [20, 35, 36]. Eliminating the transperitoneal dissection of seminal vesicles may shorten operative time by 50 min [37]. Comparable surgical results between extraperitoneal and transperitoneal LRP have been published [31, 37–41]: some authors emphasize the advantages of the extraperitoneal approach (i.e. no bowel lesions, ileus, and peritonitis) [37, 39]; while others found no differences [31, 38].

Routes of dissection

The antegrade technique starts at the bladder neck. The Foley catheter is used as a retractor to expose and cut the posterior wall of the bladder neck (Figure 90.5A). Subsequently, the vesicoprostaticus muscle is divided, exposing the vas deferens and seminal vesicles. Using the vas as a retractor, Denonvilliers' fascia is incised to dissect the posterior surface of the prostate. Proximal pedicles are clipped and divided (Figure 90.5B). Following apical dissection the dorsal vein complex (DVC) is sutured and divided. Finally, the urethra is transected (Figure 90.5C).

The retrograde technique starts at the apex with suturing and dividing of the DVC. Thereafter, the urethra is incised (Figure 90.6A). The Foley catheter is used as a retractor during prostatic posterior dissection (Figure 90.6B). Subsequently, it serves as a retractor to expose the bladder neck, which is incised to reach the vas and seminal vesicles and to control the proximal pedicles (Figure 90.6C).

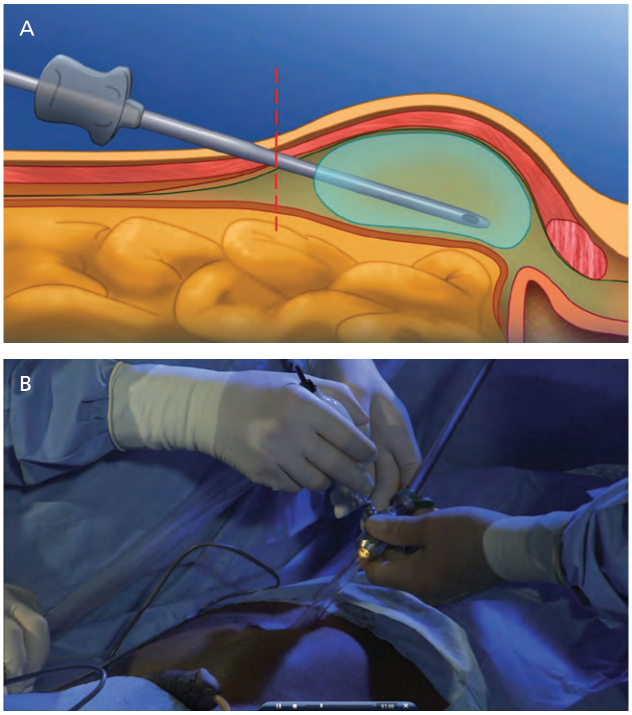


Figure 90.4 Balloon dissection of the space of Retzius under endoscopic control. (A) Schematic view. (B) Introduction of the telescope via the balloon trocar.

Retrograde versus antegrade technique

While the retrograde technique is more popular in open surgery [27, 42], laparoscopic and robotic surgeons favor the antegrade approach [33, 43]. The early control of prostatic pedicles and late division of the DVC ensure minimal bleeding.

Technical aspects for early continence

Long-term continence exceeds 90% in most laparoscopic and robotic series; however, early continence (i.e. at 3 months) is still in the range of 40–50% [3]. Several strategies have been proposed:

- Preservation/reconstruction of the puboprostatic ligaments;
- Suspension of the DVC;
- Dissection of a long urethral stump;
- Preservation of the bladder neck;
- Preservation and reconstruction of the rectourethralis muscle.

Table 90.2 Advantage and disadvantage of extraperitoneal versus transperitoneal laparoscopic radical prostatectomy.

Advantages extraperitoneal		Advantages transperitoneal
No contact with bowel		Larger room
Previous abdominal surgery		Less tension on anastomosis
Fewer problems with urine extravasation		Minimal risk of lymphocele in case of extended lymph node dissection
Gross obesity		
Simultaneous inguinal hernia repair		
	No advantage one technique over the other	
	Operating time	
	Morbidity	
	Complication rate	
	Positive surgical margin	
	Continence	

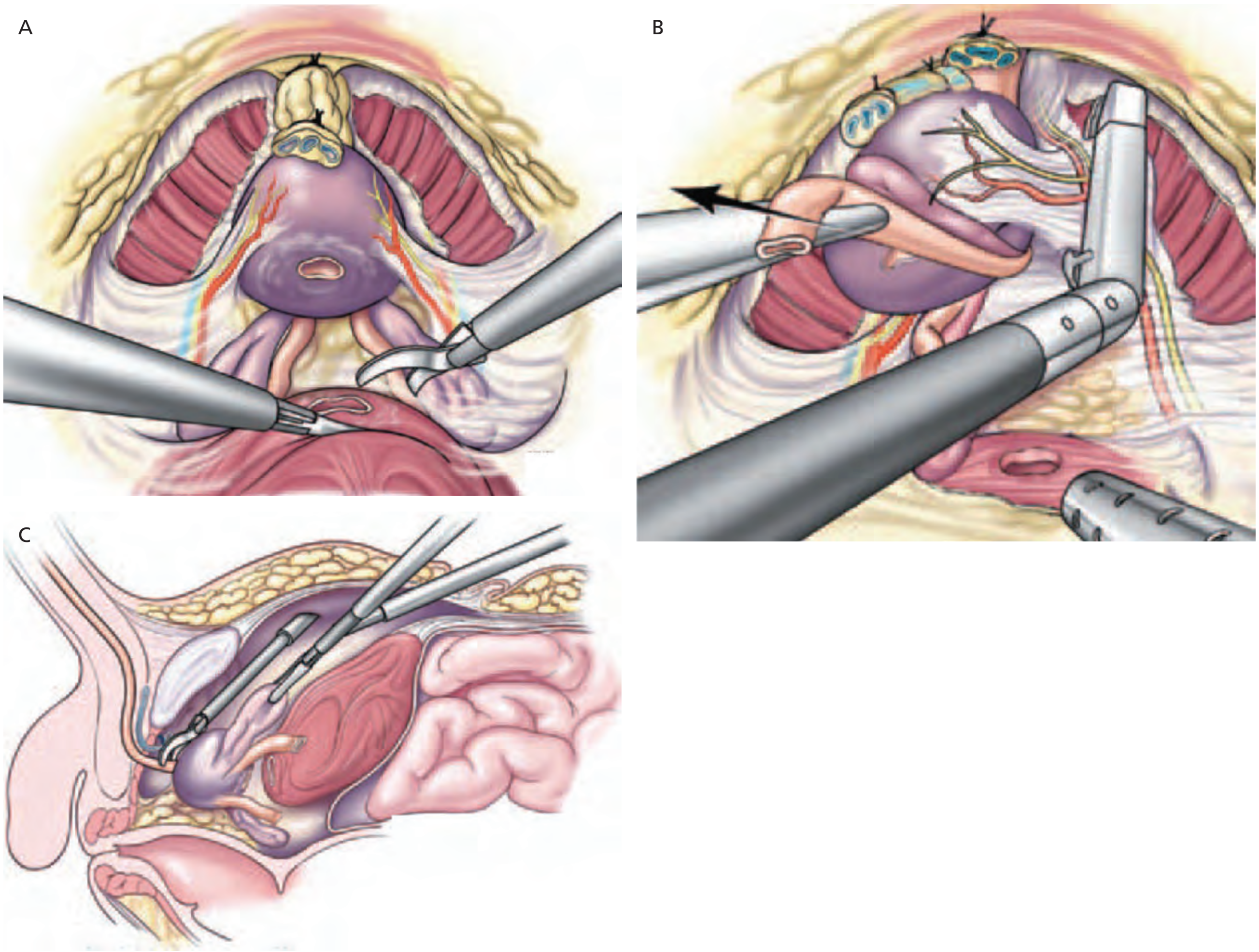


Figure 90.5 Antegrade technique of laparoscopic radical prostatectomy according to Ukimura *et al.* [22]. (A) Opening of the bladder neck and dissection of the vas deferens and seminal vesicles. (B) Dissection of the posterior surface and control of prostatic pedicles using the vas deferens as a retractor. (C) Division of the urethra. (Reproduced from Ukimura *et al.* [22], with permission.)

Recently, Takenaka *et al.* introduced the strategy of preservation of the puboprostatic collar [44]. We have added the preservation of the levator fascia to this strategy, yielding excellent short-term continence results.

Heilbronn technique for early continence (see Videos 90.1 and 90.2)

Conventional technique

Following lateral incision of the endopelvic fascia, the levator fascia is perforated, creating a dissection plane along the levator ani muscle (Figure 90.7). The levator ("periprostatic") fascia is incised secondarily to perform an interfascial nerve-sparing technique. This approach also includes division of both puboprostatic ligaments and distal ligation of the DVC (Figure 90.8).

New technique

Following medial incision of the endopelvic fascia below the puboprostatic ligaments, the avascular plane between the levator and prostatic fascia is developed (Figure 90.7). Thus, the intrapelvic branch of the pudendal nerve remains covered by levator fascia. The DVC is sutured over the mid part of the prostate to preserve the puboprostatic collar. For division of the DVC a 120° endodissector is placed over the prostatovesical junction (Figure 90.8), rotating the prostate towards the urethra, and the anterior striated sphincteric complex is reached [45]. The urethra is transected just distal to the veru montanum, preserving the rectourethralis muscle. Whenever indicated, we perform a bladder neck-sparing technique. After dividing the bladder neck, the prostatovesicle muscle is incised close to the prostate to be used for posterior reconstruction of the anastomosis.

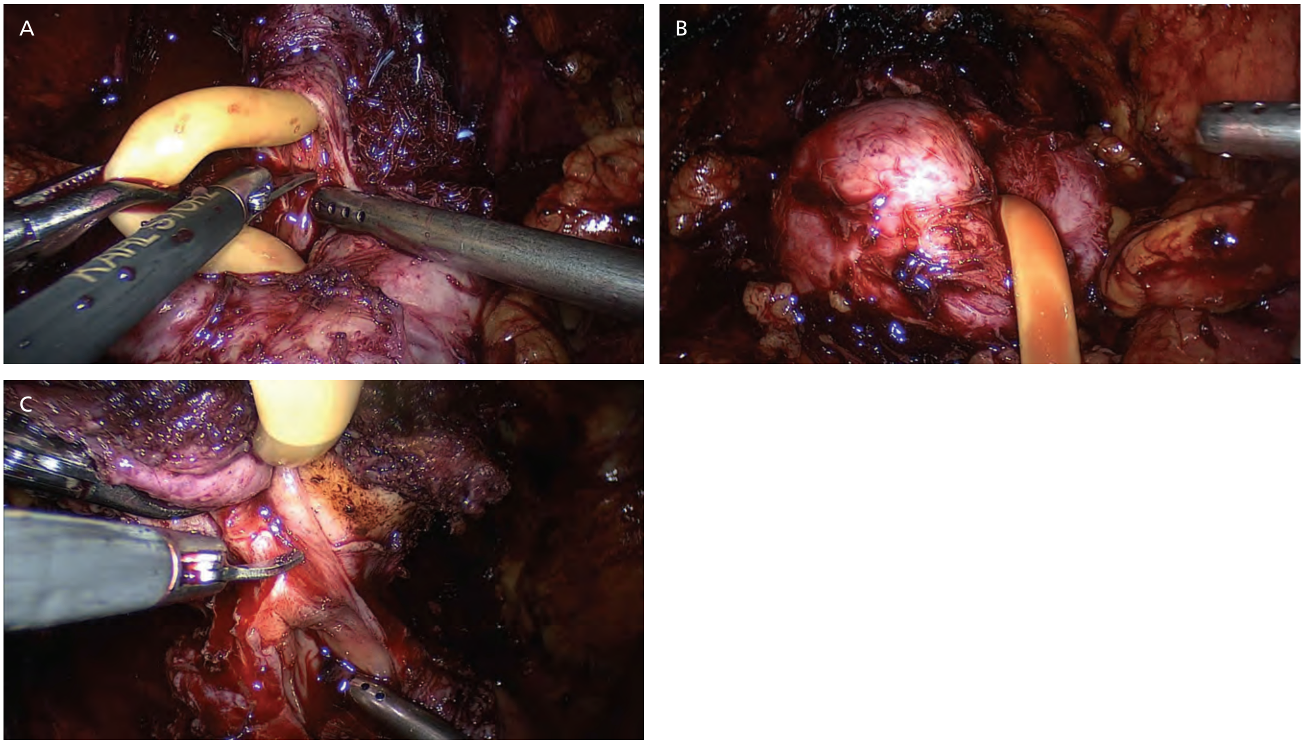


Figure 90.6 Retrograde technique of laparoscopic radical prostatectomy (Heilbronn technique). (A) Division of the urethra. (B) Posterior dissection using the Foley catheter as a retractor. (C) Bladder neck incision using the loop of the catheter as a retractor.

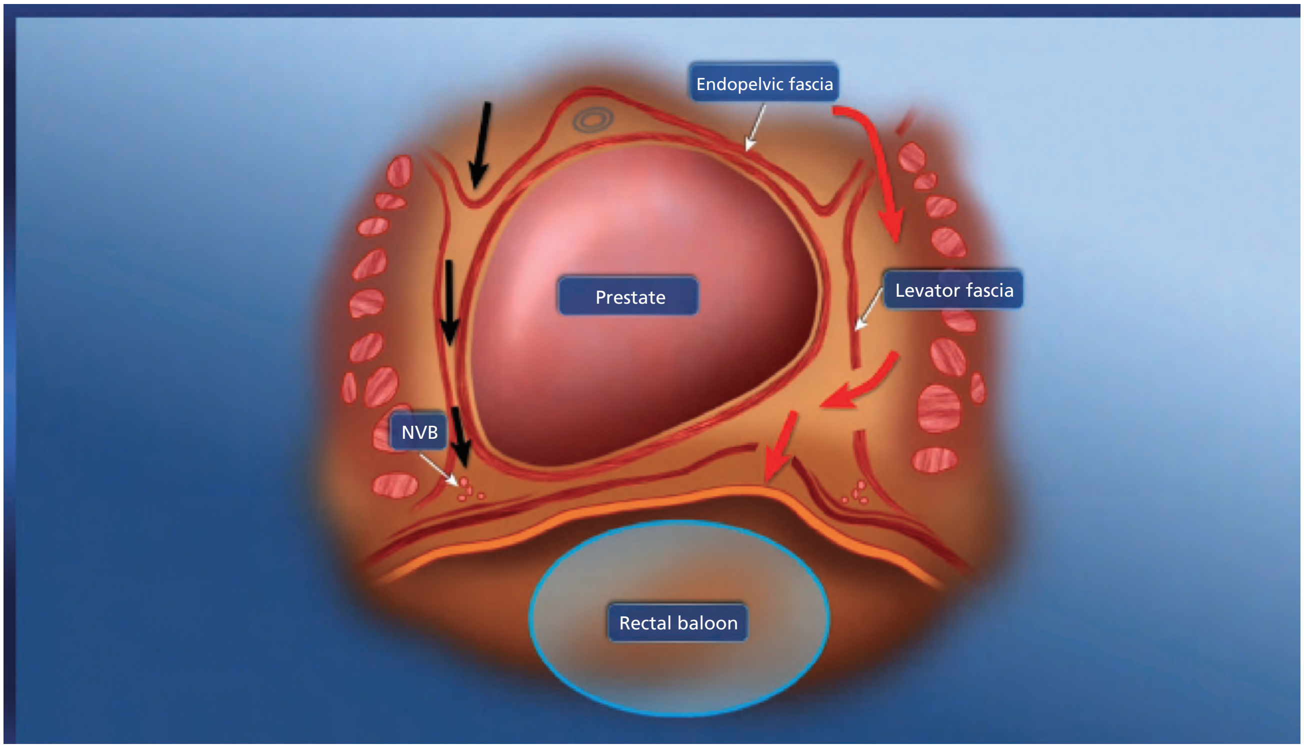

Endopelvic fascia
Prestate
Levator fascia
NVB
Rectal baloon

Figure 90.7 Incision of the endopelvic fascia. Red arrows: without preservation of the levator ani fascia (conventional technique). Black arrows: with preservation of the levator ani fascia. NVB, neurovascular bundle.

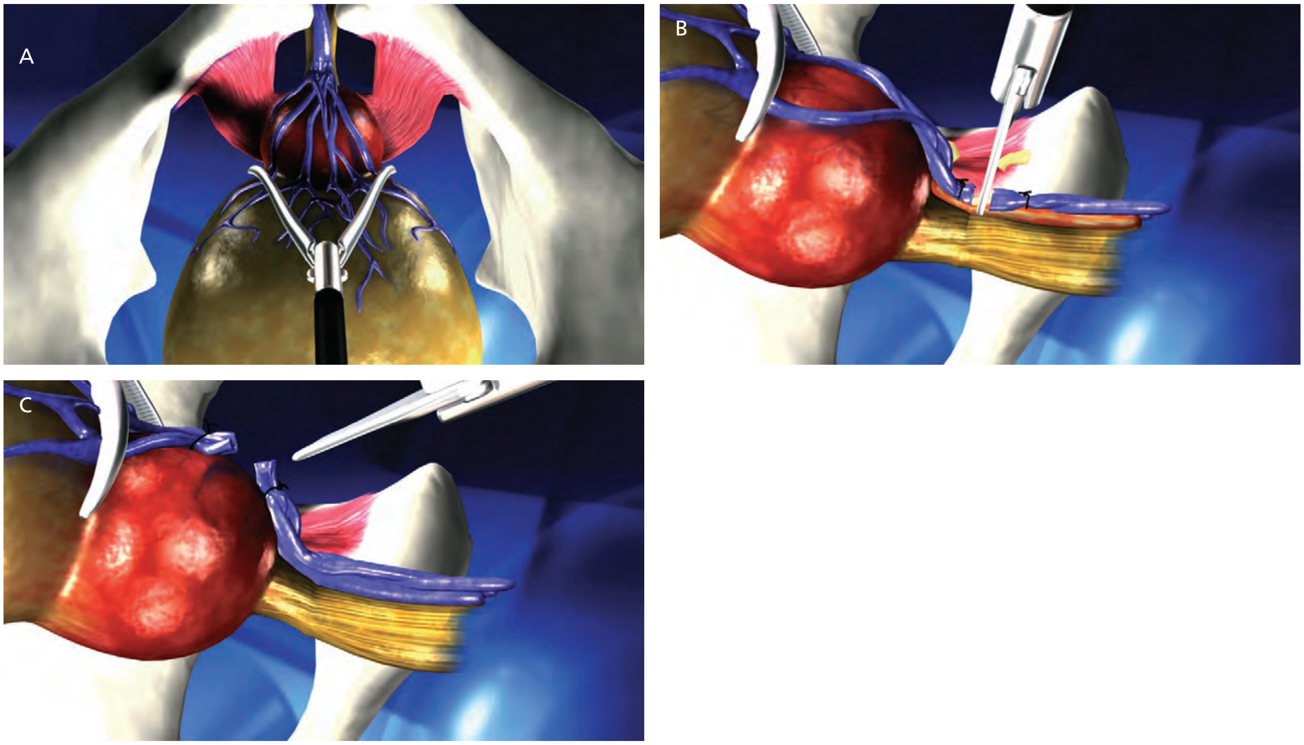


Figure 90.8 Division of the dorsal vein complex (DVC). (A) A 120° endodissector is placed over the prostatovesical junction. (B) Conventional technique: distal suturing and division of the DVC. (C) New technique: division of the DVC at the mid prostate.

Non-nerve-sparing technique

If nerve sparing is contraindicated, the NVBs are clipped distal to the urethra using 10-mm titanium clips. No Hem-o-lok clips are used to avoid migration into the anastomosis. The proximal pedicles are clipped pararectally to minimize the risk of positive margins.

Nerve-sparing techniques

Preservation of the NVBs can be performed using an antegrade or retrograde technique.

Antegrade technique

Antegrade dissection starts with the division of the proximal pedicle and release of the NVBs at the base of the prostate [8]. Finally, the bundles can be separated bluntly from the apex. The NVBs cannot easily be visualized without initially incising the levator fascia and developing the lateral NVB groove [46]. Gill *et al.* proposed intraoperative transrectal ultrasound monitoring to identify the course of the NVB [47]. Interfascial NVB dissection uses the prostatic fascia as a visible landmark, starting with its separation lateromedially [27, 42].

Retrograde technique (see Video 90.3)

Retrograde dissection reproduces the open technique with earlier release of NVBs [27, 42, 48–50]. The space between the urethra and the NVBs is dissected bluntly until Denonvilliers' fascia can be identified. The rectal balloon is inflated with 40–60 mL of air. The prostatic fascia is incised and small branches to the NVBs are controlled with 5-mm titanium clips (Figure 90.9A). The same is achieved during posterior dissection after incision of the urethra. Following division of the bladder neck, the course of the NVBs is identified to determine the clip position to control the proximal pedicle (Figure 90.9B).

Antegrade versus retrograde nerve sparing (Table 90.3)

All steps can be performed using either technique, and neither should be regarded as a pure technique [48]. Commonality exists with regards to accomplishing an interfascial dissection and early visualization of the NVBs, use of task-specific instrumentation such as fine right-angled and curved dissectors, and avoiding thermal energy during steps relevant to NVB preservation [51, 52].

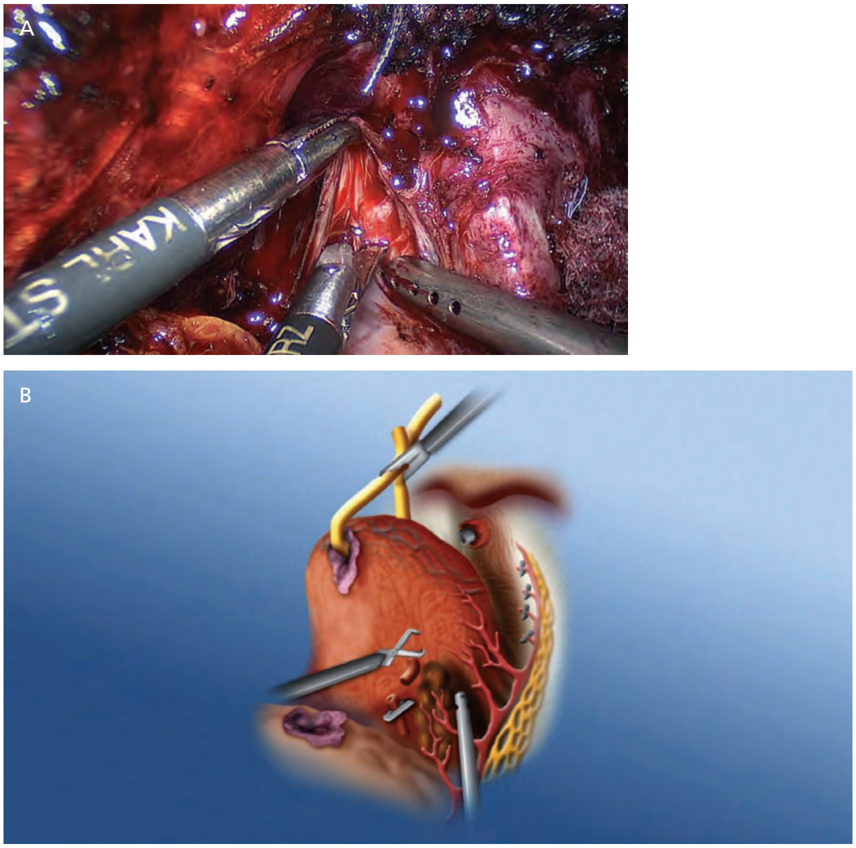


Figure 90.9 Retrograde nerve-sparing technique. (A) Early release of the neurovascular bundles at the apex using 5-mm titanium clips. (B) Controlled division of the proximal pedicle.

Table 90.3 Advantages and disadvantages of retrograde versus antegrade neurovascular bundle preservation during laparoscopic radical prostatectomy.

Technique	Advantages	Disadvantages
Retrograde	Earlier identification of neurovascular bundles (NVBs) (i.e. hemostasis at dorsal vein plexus)	Technical difficulty
	Exposure of NVBs during every step	Late control of proximal pedicle
	Direct transfer of existing techniques of open radical prostatectomy	
Antegrade	Early control of prostatic pedicle, resulting in minimal bleeding	Later identification of NVBs still covered by levator fascia
	Early control of seminal vesicle arteries	Suboptimal exposure of prostatic base during control of prostatic pedicles
	Better working angle for the instruments	
	Dissection proceeds along surgeon’s natural line of site	

Compensated for by early incision of the endopelvic fascia.

Entrapment of the specimen

The specimen is entrapped in the self-opening extraction bag (Karl Storz, Tuttlingen, Germany) by pulling the purse-string out onto the skin surface via the left 10-mm port. Thereafter, the port is reinserted parallel to the bag.

Urethrovesical anastomosis

For the urethrovesical anastomosis, the right medial port and left lateral port are used to provide an optimal angle (25–35 °) between the instruments (Figure 90.10A). The anastomosis can be accomplished by the interrupted, continuous, or single-knot technique [53].

Posterior reconstruction

Rocco and Rocco reported significant improvement of early continence following adaptation of the prostatovesicle muscle to the rectourethralis muscle [54] (Figure 90.10A–C). However, Menon *et al.* did not find any advantage over a single-knot technique alone [55]. Using our old technique of dissection lateral to the levator fascia, the Rocco suture did not improve early continence. However, it did release tension on the anastomosis as well as the NVBs.

Van Velthoven single-knot technique (see Video 90.4)

Anastomosis is performed using two bi-colored sutures (17-cm PDS 3/0 and Biosyn; RB1-needle) knotted together. We start at the 6 o'clock position on the bladder neck and then take the posterior urethra. Once the posterior part of the anastomosis is accomplished, the sutures are pulled to adapt the bladder neck and urethra (winch mechanism) (Figure 90.10D–F). An 18F catheter is inserted and the anastomosis is completed. In difficult situations, a special bougie allows insertion of a guidewire for safe placement of the catheter.

Reconstruction of the bladder neck

Posterior bladder neck reconstruction is necessary when the orifices are close (<5 mm) to the resection line (i.e. in cases of a large mid lobe). Anterior reconstruction may become necessary when bladder neck preservation is not possible or indicated.

Retrieval of the specimen

After placing the drainage tube via the right medial 10-mm port, the bag is extracted via the periumbilical incision.

Results

A systematic literature search using the terms "laparoscopic radical prostatectomy", "ergonomics", "comparative studies", "robot-assisted radical prostatectomy" (RALP), was performed in Medline, Embase and Pubmed. Inclusion criteria were randomized controlled trials (RCT) or observational series and reviews of good quality. Primary outcome parameters focused on the impact of ergonomics on performance and learning curve of the different techniques. Secondary outcome parameters were functional and oncologic outcomes after radical prostatectomy. In Heilbronn, we have performed 2200 LRPs since March 1999, including 200 with the da Vinci system [56, 57].

Twenty-seven comparative studies were identified [3]: 23 compared LRP with RRP; and four compared LRP with RALP: one randomized controlled trial [58]; nine nonrandomized prospective studies [32, 41, 59–65]; seven retrospective studies compared to contemporary series [66–72]; and five retrospective studies using historical series as controls [56, 73–76]. There are robust long-term data from major centers as well as from recent meta-analyses.

Perioperative data

Comparison of early laparoscopic series to relevant contemporary series of RRP [12, 33, 43, 77, 78] includes a major bias related to the different levels of surgical experience. Based on today's training programs, about 50 cases are necessary to learn LRP [7, 36, 79].

Operating times

Increased operating times (180–330 min) represent one of the criticisms against LRP (compared to RRP, 105–197 min; Table 90.4A) [80]. However, Frede *et al.* showed a decrease in operative time from 332 min for the first 50 cases to 196 min for the last 50 cases after 1000 procedure [34]. With experience, there was also a significant decrease in operating time with the extraperitoneal approach [36, 81].

Blood loss and transfusion rates

Compared to RRP, LRP demonstrated a significantly lower blood loss (189–1100 mL vs 550–1550 mL) and transfusion rate in cumulative analysis (Table 90.4B) [41, 55, 58, 60, 66, 68, 73, 82, 83]. In one study comparing 1134 LRP versus 3458 RRP cases, the transfusion rate was 4% versus 55% [84]. Also, the study by Hu revealed a 20% transfusion rate for RRP versus 4% for minimally invasive techniques [85].

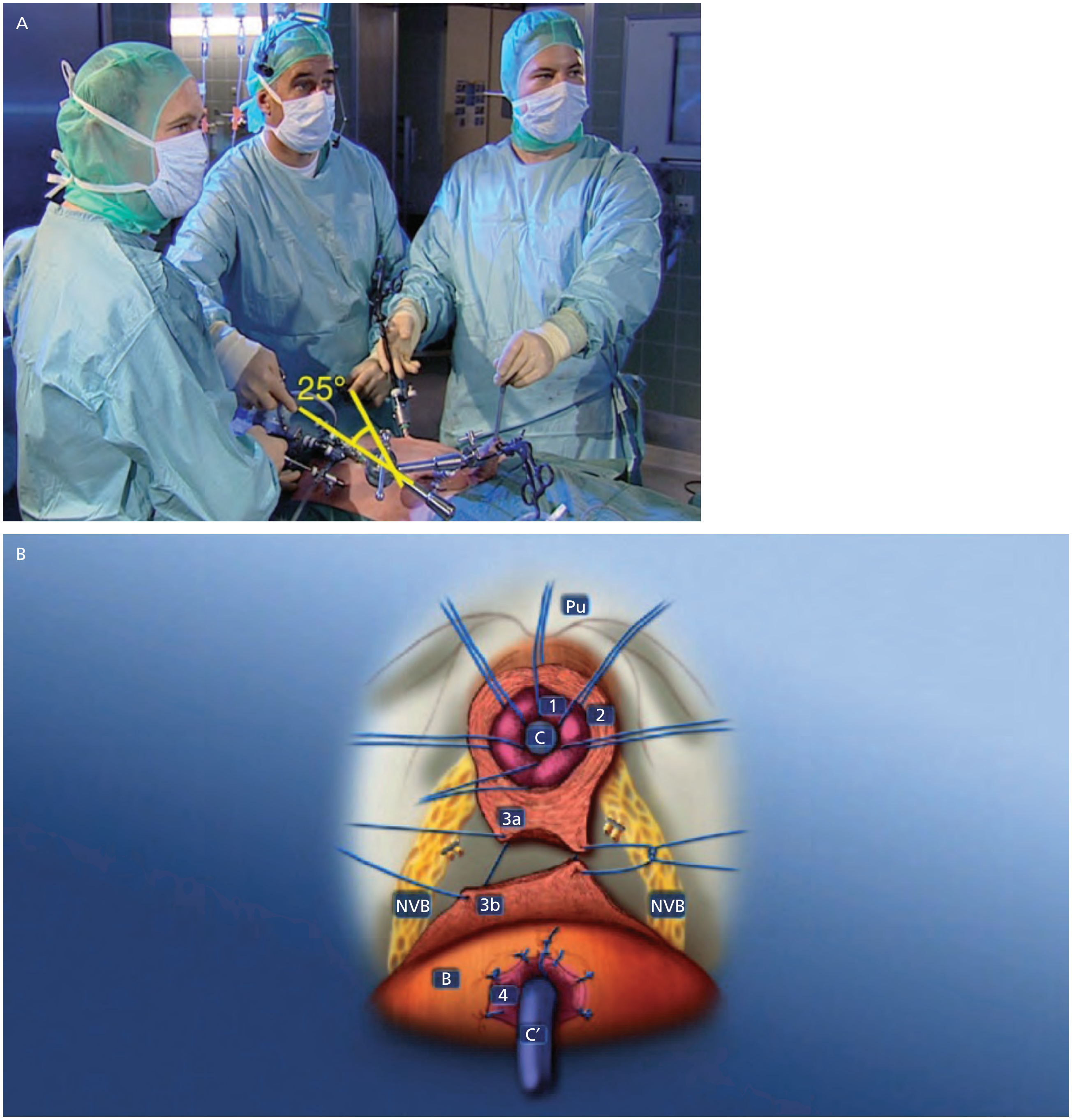


Figure 90.10 Urethrovesical anastomosis. (A) Suturing using the right medial port for the needle driver to achieve an appropriate angle between the instruments. (B) Schematic posterior reconstruction according to Rocco and Rocco [54], with adaptation of the vesicoprostatic muscle to the rectourethralis muscle and posterior plate. B, bladder; NVB, neurovascular bundle; C, catheter; Pu, pubic bone; 1, lithosphincter; 2, rhabdosphincter; 3a, rectourethralis muscle; 4, bladder neck. (C) Rocco stitch. (D) Single-knot technique according to van Velthoven using a bi-colored suture. Urethral stitch (inside–outside).
(E) Bladder neck stitch (outside–inside) at 4 o’clock. (F) Adaptation of the posterior part of the anastomosis using the winch principle.

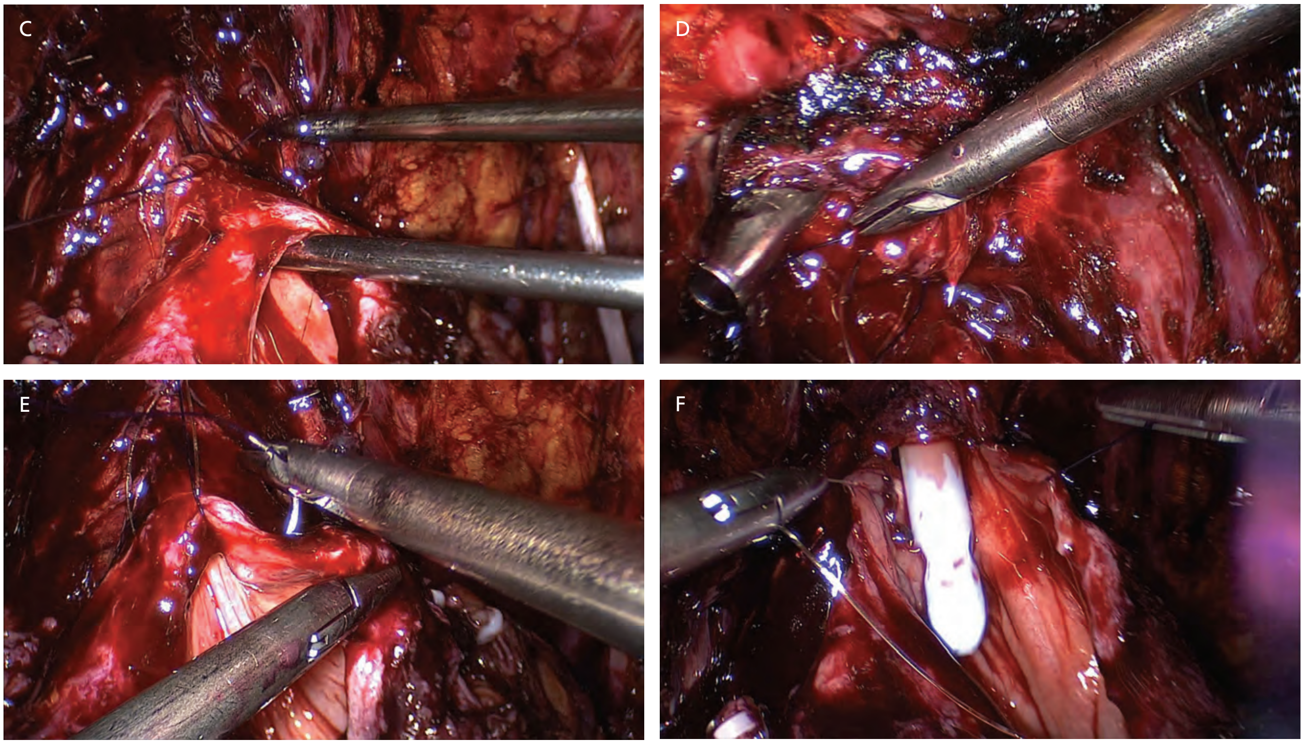


Figure 90.10 *Continued*

Postoperative pain

Most of the studies used a visual analog scale or the morphine equivalent requirement [41, 56, 58, 59, 64, 69, 70]. Pain scores were slightly lower during postoperative day 1 in patients undergoing LRP [58]. There was no statistically significant difference in the required morphine sulfate equivalent. The level of postoperative pain might be affected by epidural infusion of analgesic following RRP [86].

Catheter times and hospital stay

Overall, catheterization times ranged between 6 and 14 days after LRP and 5 and 22 days after RRP [56, 58, 59, 70, 74]. The catheter was withdrawn early in a higher percentage of LRP patients compared to RRP. Length of stay in hospital was significantly shorter for LRP patients [41, 56, 59, 65, 70, 74, 78]. However, there was a wide variation in length of stay due to the differences in economic health systems and cultural background.

Complications

We classified complications according to the modified Clavien system [86] (Table 90.5). In a study with follow-up of 37 months, Rabbani *et al.* reported 19.9% Clavien 1–2 complications following RRP compared to 37.3% after LRP [87]. However, they listed transfusion rates of 55% after RRP and 4% after LRP separately. Therefore, many patients receiving transfusions were not registered as Clavien 2. Novara *et al.* observed 19% Clavien 1–2 (including 5.3% transfusions), similar to the rates in our series (21.7% including 10.4% transfusions) [3, 88]. In Rabbani *et al.*'s series, Clavien 3–5 complications occurred in 6.4% after RRP and 8.9% after LRP, compared to 11.4% in our series (Table 90.5).

The low conversion rates (1.9–2.2%) in all major series reflect the careful introduction of LRP [20, 59]. In a recent multicenter study, technical reasons or unclear anatomy of the tumor were the reasons for conversion to open surgery [20]. A single retrospective study reported a lower rate of anastomotic strictures in LRP compared to RRP [56]. No differences were found between LRP and RALP.

Predictive factors for complications (Table 90.6)

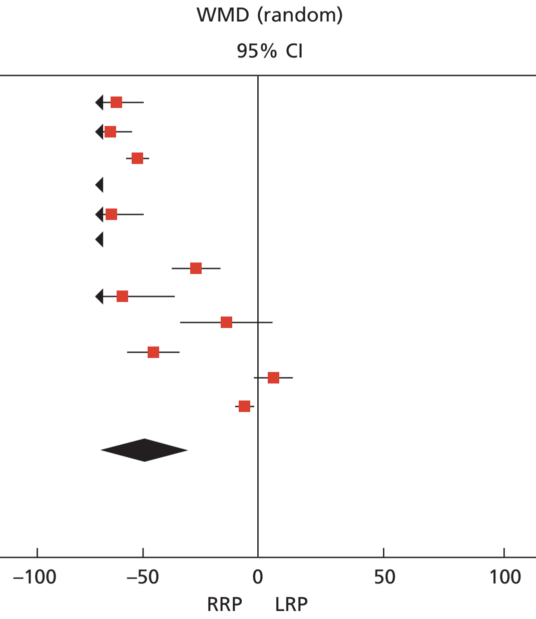
Novara *et al.* identified prostate volume greater than 50 cm as an independent predictor of complications [88], but Zorn *et al.* did not find any impact of prostate volume for RALP [89]. Additionally operating time longer than 4 h, non-nerve sparing technique, and transperitoneal access predicted a higher rate of complications. However, there is a relationship between the institutional learning curve and these factors, with the number of cases performed by the being a predictive factor [88].

Table 90.4 Comparison of intraoperative outcome following laparoscopy (LRP) and retropubic radical prostatectomy (RRP) (meta-analysis according to Ficarra *et al.* [80]). (A) Operating times (min). (B) Transfusion rates.

Study or sub-category	N	RRP Mean (SD)	N	LRP Mean (SD)	Weight %	WMD (random) 95% CI
Salomon (2002)	145	197.00 (56.00)	137	285.00 (87.00)	8.38	–88.00 [–105.18, –70.82]
Anastasiadis (2003)	70	179.00 (40.00)	230	271.00 (78.00)	8.49	–92.00 [–105.76, –78.24]
Artibani (2003)	50	105.00 (17.00)	71	180.00 (20.00)	8.64	–75.00 [–81.62, –68.38]
Bhayani (2003)	24	168.00 (33.00)	33	348.00 (72.00)	7.91	–180.00 [–207.89, –152.11]
Rassweiler (2003)	219	196.00 (74.00)	219	288.00 (98.00)	8.41	–92.00 [–108.26, –75.74]
Roumeguere (2003)	77	168.00 (52.00)	85	288.00 (67.00)	8.33	–120.00 [–138.38, –101.62]
Atallah (2004)	115	161.00 (37.50)	59	201.00 (46.20)	8.49	–40.00 [–53.64. –26.36]
Remzi (2005)	41	195.00 (72.00)	39	279.00 (70.00)	7.74	–84.00 [–115.12, –52.88]
Remzi (2005)	41	195.00 (72.00)	41	217.00 (51.00)	7.95	–22.00 [–49.01, 5.01]
Guazzoni (2006)	60	170.00 (34.20)	60	235.00 (49.90)	8.44	–65.00 [–80.31, –49.69]
Poulakis (2007)	70	150.00 (30.00)	72	144.00 (36.00)	8.56	6.00 [–4.89, 16.89]
Touijier (2008)	818	188.00 (41.00)	612	199.00 (47.00)	8.67	–11.00 [–15.66, –6.34]
Total (95% CI)	1730		1658		100.00	–71.20 [–97.35, –45.05]

Test for heterogeneity: Chi^2 = 635.31, df = 11 ($P < .00001$), I^2 = 98.3%

Test for overall effect: Z = 5.34 ($P < .00001$)



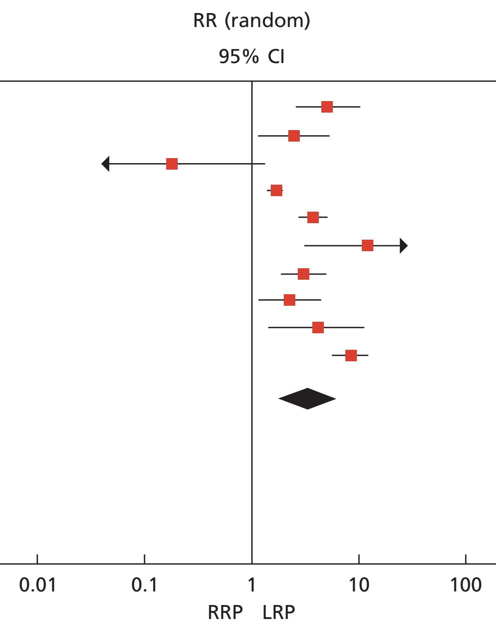
WMD, weighted mean difference.

A

Table 90.4 *Continued*

Study or sub-category	RRP n/N	LRP n/N	Weight %	RR (random) 95% CI
Salomon (2002)	38/145	4/137	10.46	8.89 [3.29, 24.48]
Anastasiadis (2003)	6/70	6/230	10.09	3.29 [1.09, 9.87]
Artibani (2003)	0/50	8/71	4.64	0.08 [0.00, 1.41]
Rassweiler (2003)	122/219	66/219	12.61	1.85 [1.46, 2.34]
Rassweiler (2003)	122/219	21/219	12.28	5.81 [3.80, 8.87]
Brown (2004)	31/60	1/60	6.94	31.00 [4.37, 219.84]
Guazzoni (2006)	32/60	8/60	11.57	4.00 [2.01, 7.95]
Jurczck (2007)	21/240	5/163	10.64	2.85 [1.10, 7.41]
Poulakis (2007)	13/70	2/72	8.74	6.69 [1.57, 28.56]
Touijier (2008)	338/818	14/612	12.04	18.06 [10.69, 30.51]
Total (95% CI)	1951	1843	100.00	4.72 [2.20, 10.14]

Total events: 723 (RRP), 135 (LRP)
Test for heterogeneity: $\text{Chi}^2 = 108.91$, df = 9 ($P < .00001$), $I^2 = 91.7\%$
Test for overall effect: Z = 3.98 ($P < .0001$)



RR, relative risk.
B

Oncologic results

Positive margins

Comparative and cumulative studies have provided data on positive surgical margin (PSM) rates ranging from 11% to 37% after RRP, 11–30% after LRP, and 9.6–26% after RALP (Table 90.7). Accordingly, Guazzoni *et al.* demonstrated overlapping PSM rates [58]. No differences were found between LRP and RALP, considering early [90] and more advanced phases [91] of the RALP learning curves.

Prostate-specific antigen recurrence

There are only few long-term studies. Guillonneau *et al.* reported an overall actuarial biochemical progression-free survival rate of 90.5% at 3 years [92]. The rates were 92% for pT2a, 88% for pT2b, 77% for pT3a, and 44% for pT3b. Our data revealed overall 10-year PSA-recurrence-free survival of 65%, including 80% for pT2 and 51% for pT3–4 (Figure 90.11A). Compared to RRP, the oncologic outcome was similar (Table 90.8).

The multicenter study published by Vickers *et al.* analyzed the learning curve of LRP based on the PSA-recurrence-free status [117]. In an earlier RRP study, it was identified that 250 cases need to be performed by a surgeon to achieve a plateau. In the LRP series including more than 5000 patients, this plateau was reached after 750 patients. However, there was an ongoing improvement (Figure 90.12), indicating some advantages attributed to videoendoscopic surgery.

Survival data

Clinical progression-free 10-year-survival was 97% for pT2 and 81% for pT3 (Figure 90.11B). We observed a local recurrence in 3% of pT2 and 13% of pT3/4 cases managed mostly by early adjuvant irradiation. Overall, 10-year survival was 96.8% for pT2 and 92.2% for pT3 (Figure 90.11C) (unpublished data)].

Functional results

Evaluation of functional results after radical prostatectomy is difficult, because only a few comparative studies have used validated questionnaires [70].

Continence

To determine *early* continence, we introduced the urine loss ratio (ULR) based on a micturition protocol following catheter removal [118]. If ULR is below 0.05, the probability that the patient will be continent after 3 weeks is 89%. Using ULR, we compared our previous technique with and without posterior reconstruction and found no impact on ULR (52% vs 54%). When using

Table 90.5 (A) Complication rates in consecutive cases (n = 2200) of laparoscopic radical prostatectomy at a single center. (B) Comparison of complication rates of laparoscopic and retropubic prostatectomy in the literature.

	Clavien classification*	Within 6 weeks		Within follow-up of 50 months	
No reinterventions necessary	1	6.8 %	= 21.7 %	–	= 21.7 %
	2	14.9 %		–	
Reinterventions necessary	3a	3.6 %	= 5.1 %	–	= 9.8 %
	3b	1.5 %		4.7 %	
	4a	1.5 %	= 1.6 %	–	= 1.6 %
	4b	0.1 %		–	
	5	0.1 %	= 0.1 %	–	= 0.1 %

*Clavien 1: any deviation from the normal intraoperative or postoperative course, including the need for pharmacologic treatment other than antiemetics, antipyretics, analgesics, diuretics, electrolytes, or physiotherapy; Clavien 2: complications needing only the use of intravenous medications, total intravenous nutrition, or blood transfusion; Clavien 3a: complications needing surgical, endoscopic or radiologic intervention under local anesthesia; Clavien 3b: complications needing surgical, endoscopic or radiologic intervention under general anesthesia; Clavien 4a: life-threatening complications requiring intensive care unit (ICU) management: single organ dysfunction; Clavien 4b: life-threatening complications requiring ICU management: multiorgan dysfunction; Clavien 5: death of the patient.

A

Complication	Present series (see Table 90.5A) LRP (%)	Rabbani *et al.* 2010 [87]		Literature [87]	
		RRP (%)	LRP (%)	RRP (%)	LRP (%)
Urinoma/urinary leak	1.4	2.9	8.7	0.2–6.7	1.0–13.6
Bladder neck contracture	4.6	5.5	0.7	1.0–17.9	0.2–5.3
Urinary retention	3.0	3.6	3.0	0.6–2.0	0.8–5.9
Hydronephrosis	0.8	0.9	1.9	0.2–1.0	0.0–0.4
Ureteral injury	0.1	0.5	0.2	0.1–0.8	0.2–0.5
Bladder calculus/suture/clip	0.15	0.6	0.2	N/A	0.8
Lymphocele	0.7	3.0	5.4	0.1–6.9	0.0–1.1
Abscess	0.1	0.7	1,7	0.4–1.7	0.0–0.7
Rectal/bowel injury	2.1*	0,7	0,4	0.4–4.9	0.0–1.4
Wound infection	0.5	2.3	3.8	0.6–13.8	0.0–1.0
Cardiac ischemia	0.15	0.2	0.4	0.0–1.0	0.0–0.7
Cardiac arrhythmia	0.2	0.9	0.7	0.2–4.8	N/A
Respiratory distress	0.3	0.6	0.6	0.5–1.2	0.2–0.7
Pneumonia	0	0.3	0.4	0.2–1.4	0.0–0.3
Ileus	0.3	0.3	2.1	0.3–3.0	0.3–5.3
Acute renal insufficiency	0.05	0.7	1.0	0.2–0.4	0.0–0.3
Venous thromboembolism	0.5	1.9	2.0	0.4–1.3	0.0–2.4
Urinary tract infection	2.1	2.8	7.8	0.1–3.0	1.0–2.4
Anemia needing transfusions	14.8	55.0	4.0	N/A	N/A
Total	**33.1****	**27.5**[†]	**39.0**[†]	**N/A**	**M/A**

*1.4% of cases were managed conservatively (intraoperative suture of superficial bowel/rectal injury followed by parental nutrition for several days and prolonged catheterization time).

**Including blood transfusions. Excluding patients with anemia as only complication, total complication rate amounts to 22.7%.

[†] Excluding blood transfusions.

B

Table 90.6 Significant prognostic factors predictive for complications of laparoscopic radical prostatectomy.

Factor		% Without complications	% Clavien 1–2	% Clavien 3–5	*P*
Weight of specimen (g)	≤50	68.5	19.9	11.6	.002
	>50	61.7	27.2	11.1	
Nerve sparing	Non-nerve sparing	63.5	22.7	13.8	<.001
	Unilateral nerve sparing	69.9	18.7	11.4	
	Bilateral nerve sparing	75.0	16.3	8.7	
Access	Transperitoneal	65.5	21.4	13.1	.005
	Extraperitoneal	72.9	17.6	9.5	
Operating time (h)	≤4	73.6	17.5	8.9	.023
	>4	66.6	20.7	12.7	

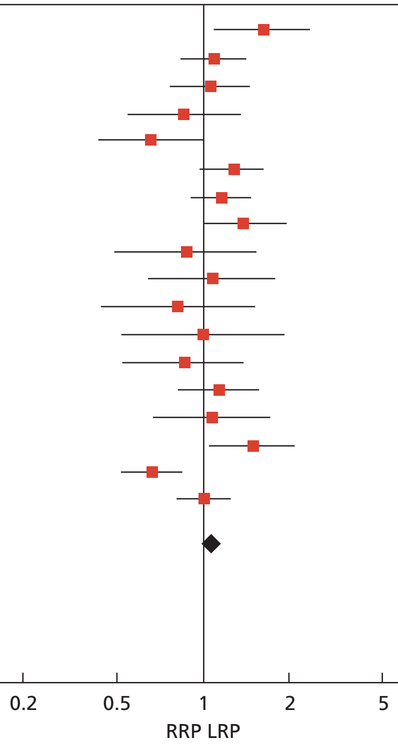
Table 90.7 Comparison of positive surgical margin rate for laparoscopic (LRP) and retropubic radical prostatectomy (RRP) (meta-analysis according to Ficarra *et al.* [80]).

Study or sub-category	RRP n/N	LRP n/N	Weight %	RR (fixed) 95% CI
Fremont (2002)	36/139	19/139	3.67	1.89 [1.15, 3.14]
Salomon (2002)	46/145	39/137	7.75	1.11 [0.78, 1.59]
Anastasiadis (2003)	20/70	61/230	5.50	1.08 [0.70, 1.65]
Artibani (2003)	12/50	21/71	3.35	0.81 [0.44, 1.49]
Egawa (2003)	14/49	17/34	3.88	0.57 [0.33, 1.00]
Rassweiler (2003)	63/219	46/219	8.89	1.37 [0.98, 1.91]
Rassweiler (2003)	63/219	52/219	10.05	1.21 [0.88, 1.66]
Roumeguere (2003)	31/77	22/85	4.04	1.56 [0.99, 2.44]
Brown (2004)	10/60	12/60	2.32	0.83 [0.39, 1.78]
Martorana (2004)	13/50	12/50	2.32	1.08 [0.55, 2.14]
Remzi (2005)	8/41	10/39	1.98	0.76 [0.34, 1.73]
Remzi (2005)	8/41	8/41	1.55	1.00 [0.42, 2.41]
Guazzoni (2006)	13/60	16/60	3.09	0.81 [0.43, 1.54]
Jurczok (2007)	47/240	27/163	6.22	1.18 [0.77, 1.82]
Poulakis (2007)	16/70	15/72	2.86	1.10 [0.59, 2.05]
Silva (2007)	37/89	22/90	4.23	1.70 [1.10, 2.64]
Terakawa (2008)	52/220	54/132	13.05	0.58 [0.42, 0.79]
Touijier (2008)	92/816	69/612	15.24	1.00 [0.75, 1.34]
Total (95% CI)	2655	2453	100.00	1.08 [0.97, 1.19]

Total events: 581 (RRP), 522 (LRP)

Test for heterogeneity: Chi^2 = 37.42, df = 17 (*P* = .003), I^2 = 54.6%

Test for overall effect: Z = 1.38 (*P* = .17)



RR, relative risk.

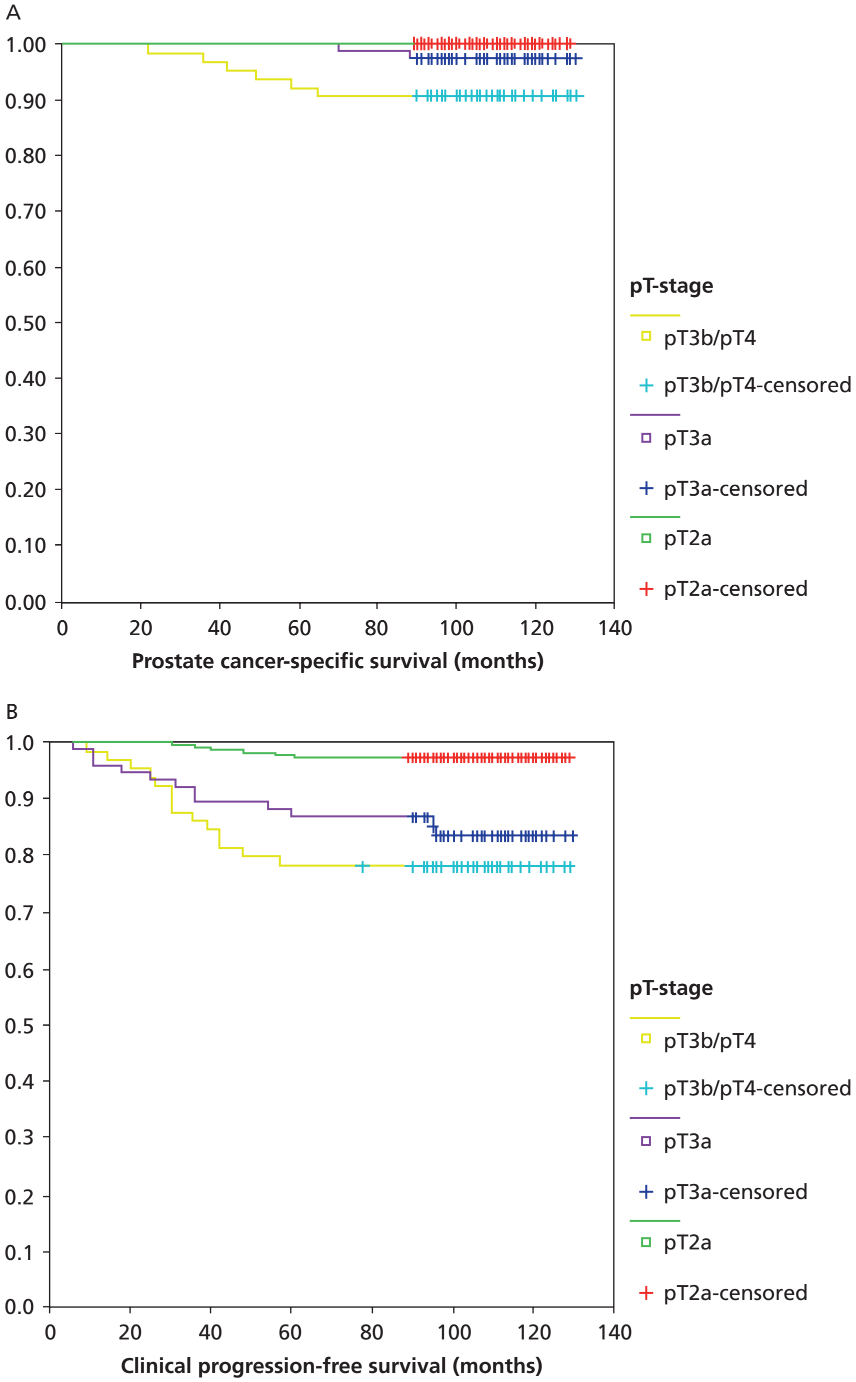


Figure 90.11 Oncologic outcome of laparoscopic radical prostatectomy at 10 years follow-up (Heilbronn experience). (A) Prostate-specific antigen (PSA) recurrence. (B) Clinical progression-free survival. (C) Overall survival.

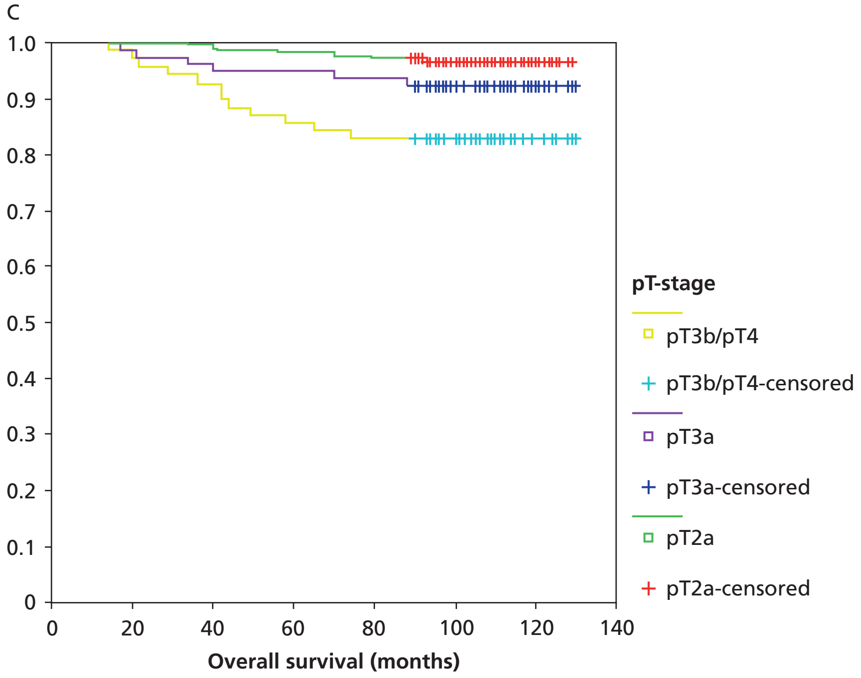


Figure 90.11 *Continued*

the Heilbronn approach, the rate of minimal urine loss increased to 92% (Table 90.9).

One comparative study has shown higher *long-term* continence rates in RRP patients [65]. When evaluating the learning curve of LRP, continence recovery was better with RRP [68]. Patients undergoing LRP had a two-fold higher risk of being incontinent [65]. In major series from referral centers, however, 12-month continence rates (66–95% vs 60–93%) overlapped for RRP and LRP (Table 90.10A). The only study comparing urinary continence after LRP and RALP failed to show any difference in 6-month rates (118) (Table 90.10B).

Erectile function

Two studies have used validated questionnaires such as the International Index of Erectile Function (IIEF) [61, 119]. Three studies have compared RRP and LRP [60, 61, 65] and none showed any advantage favoring LRP. A single retrospective study comparing historical series after LRP and RALP demonstrated a statistically insignificant trend in favor of RALP [119]. No comparative study showed any significant advantage for LRP at 12 months (42–76% vs 10–93%).

Cost-effectiveness

Three cost calculations from the USA are available (120–122). They suggested that LRP was more expensive than RRP (RRP US$5253–8596; LRP US$5058–10414). However, with the use of nondisposable instruments, completing LRPs in 3.4h, and discharging patients on postoperative day 2, cost equivalence between the two could be achieved [120]. Lotan *et al.* included RALP in their analysis and found a cost advantage of RRP of US$487 and US$1726 over LRP and RALP, respectively [122]. The shorter operative time (140min vs 160min) and length of stay (1.2 days vs 2.5 days) did not compensate for the added expense of RALP.

Perspectives on laparoscopic radical prostatectomy

Ergonomic deficiencies

During LRP, surgeons suffer from high levels of mental and physical stress. After 4–5h, the fatigue syndrome sets in, characterized by mental exhaustion, and reduced dexterity and capacity for good judgment [123, 124]. Back pain is common [124]. The force required to control the laparoscopic instruments can be six times greater, and the problem is magnified further by the nonergonomic design of the handles [125]. Also, the assistant is in a high-risk ergonomic position, created by the left leg bearing 70–80% of body weight over time [126]. Even if the da Vinci system has optimized the ergonomics of laparoscopic surgery, it still has limitations and is not cost-effective. Therefore, a significant

Table 90.8 Comparison of positive surgical margins after laparoscopic (LRP) and retropubic radical prostatectomy (RRP) (meta-analysis according to Ficarra *et al.* [80]).

Positive margin (%)				PSA recurrence-free survival (%) 1 – 2									Clinical progression free					
					pT2				pT3 + pT4				Prostate-confined disease			Extraprostatic disease		
Study	Number of patients	pT2	pT3	Study	3 years	5 years	8 years	10 years	3 years	5 years	8 years	10 years	Study	5 years	10 years	Study	5 years	10 years
Laparoscopic radical prostatectomy																		
Guillonneau *et al.* 2003 [91]	350	11.1	37.3	Salomon *et al.* 2002 [75]	90.4	–	–	–	–	–	–	–	–	–	–	–	–	–
Stolzenburg *et al.* 2004 [93]	300	9.2	30.3	Guillonneau *et al.* 2003 [91]	90.4	–	–	–	77.7[a]	–	–	–	–	–	–	–	–	–
Rozet *et al.* 2005 [94]	599	14.6	25.6	Secin *et al.* 2006 [95]	–	81.0	–	–	–	53.0[b]	–	–	–	–	–	–	–	–
Martinez-Pineiro *et al.* 2006 [96]	604	19.2	53.2	Goeman *et al.* 2006 [97]	–	89.7	–	–	–	58.6[c]	–	–	–	–	–	–	–	–
Lein et al., 2006 [98]	1000	14.9	54.5	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–
Touijer *et al.* 2007 [99]	485	8.2	17.2	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–
Rassweiler *et al.* 2010 (unpublished data)	2200	6.7	41.3	Rassweiler *et al.* 2010 (unpublished data)	94.1	88.3	–	82.9	80.0[b]	64.9[c]	–	53.0	Rassweiler *et al.* 2010 (unpublished data)	97	97	Rassweiler *et al.* 2010 (unpublished data)	84[b]	81[b]
Retropubic radical prostatectomy																		
Huland 2001 [100]	789	14.9	36.5	Catalona and Smith 1998 (RRP) [101]	92.5	90.0	–	–	78.7	68.7	–	–	Trapasso *et al.* 1994 [102]	93	–	Gerber *et al.* 1997 [103]	72	32
Artibani *et al.* 2003 [67]	50	14	43.6	Ward *et al.* 2004 [104]	–	82.0	–	73.0	–	58.0	–	39.0	Catalona and Smith 1994 [105]	96	70	Van der Ouden *et al.* 1998 [106]	59	31
Swindle *et al.* 2005 [107]	1389	7	23	Haukaas *et al.* 2006 [108]	86.0	76.0	–	–	57.0	46.0	–	–	Ohori *et al.* 1994 [109]	94	90	Ward *et al.* 2005 [110]	85	73
Guazzoni *et al.* 2006 [58]	60	18.3	31.2	Chun *et al.* 2006 [111]	–	87.1	80.2	–	–	44.2	34.5	–	Walsh *et al.* 1994 [112]	97	85	Carver *et al.* 2006 [113]	86	–
Eastham *et al.* 2007 [114]	2242	7	22	Carini *et al.* 2008 [115]	–	91.1	84.1	–	–	73.8	69.9	–	–	–	–	Hsu *et al.* 2007 [116][a]	96	85

[a] only pT3a;
[b] pT3a + pT3b + pT4;
[c] pT3a + pT3b.

effort needs to be invested to improve the ergonomics of laparoscopy.

Technical advances

The recent introduction of high-definition technology has significantly improved depth perception. In 1999, a special chair was proposed with pedal switches to improve the ergonomics [127]. Since 2005, we have used a surgical support during LRP to reduce the stress on the knee joints; however, during anastomosis the surgeon needs to stand up. Recently, a specially designed ergonomic body support consisting of a platform with foot pedal, a semi-standing support, a remote control, and a chest support was presented [128]. Electomyography results showed an average reduction of stress on the muscle of 44% for the erector spinae, 20% for the semi-tendinosus, and 74% for the gastrocnemious muscle when using the chest support. The average muscle reduction using the semi-standing support was 5%, 12%, and 50%, respectively. In 2010, first experiences were published for the use of a platform (Ethos), which allows the surgeon to sit over the patient's head. This may overcome all physical stress problems concerning rotation, unstable standing, and weight balance in the future.

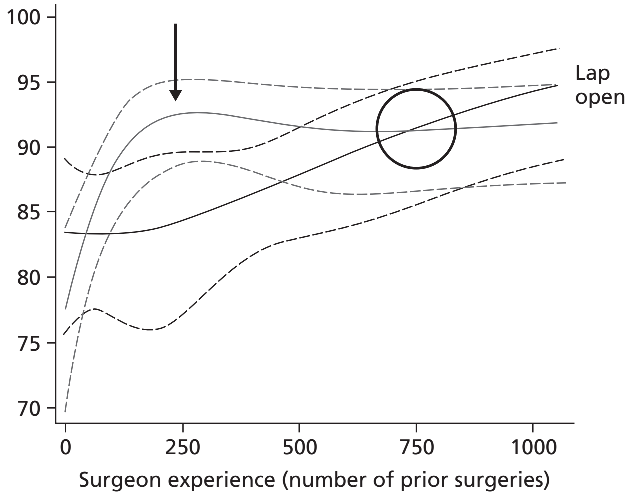


Figure 90.12 Comparison of learning curves of laparoscopic (LRP) and retropubic radical prostatectomy (RRP) (reproduced from Vickers *et al.* [117], with permission).

LESS radical prostatectomy

Laparoendoscopic single-site surgery (LESS) has received significant attention in general surgery, where transvaginal cholecystectomy is performed increasingly. There are also first reports of LESS radical prostatectomy using a periumbilical incision for port placement [129]. Interestingly, marketing plays also an important role in offering an "incisionless" removal of the gallbladder or prostate. The development of prebent and flexible instruments as well as steerable ports will significantly impact the ergonomics of this approach.

Conclusions

There is no doubt that LRP has lost the race against RALP in the USA. Nevertheless, LRP has proven to be safe and provides at least similar functional and oncologic outcomes to RRP. It will be interesting to see if future improvements, particularly concerning the ergonomics of the procedure, will impact on the role of LRP worldwide.

Table 90.9 Impact of posterior reconstruction versus preservation of puboprostatic collar and levator ani fascia on early continence based on the urine loss ratio (ULR) following catheter removal (same surgeon, <70 years, pT2/3, bilateral nerve sparing).

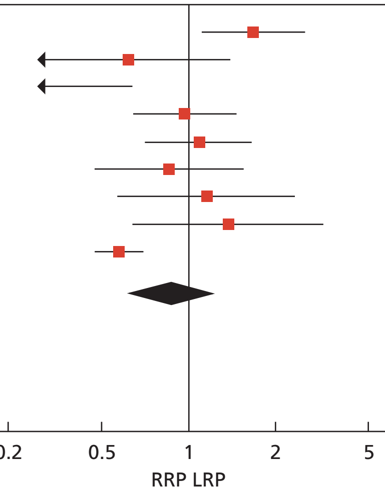
ULR*	No posterior reconstruction No preservation of puboprostatic collar	Posterior reconstruction No preservation of puboprostatic collar	Posterior reconstruction Preservation of puboprostatic collar
<0.02	55.2%	52.3%	92.3%
<0.05	22.7%	18.2%	7.7%
<0.11	9.4%	18.2%	–
<0.16	6.4%	9.1%	–
Total	92.7%	97.8%	100%

*Urine loss weight in pads/micturition volume (according to Hu *et al.* [85]).

Table 90.10 Comparison of continence after laparoscopic (LRP) and retropubic radical prostatectomy (RRP). (A) 12-month continence rate (meta-analysis according to Ficarra ***et al.*** [80]. (B) Continence according to first day urine loss ratio according to Ates *et al*. [118].

Study or sub-category	RRP n/N	LRP n/N	RR (random) 95% CI	Weight %	RR (random) 95% CI
Anastasiadis (2003)	16/70	25/230		13.01	2.10 [1.19, 3.71]
Artibani (2003)	3/14	0/20		0.25	0.54 [0.17, 1.67]
Egawa (2003)	3/41	14/34		0.09	0.18 [0.06, 0.57]
Rassweiler (2003)	22/219	22/219		13.07	1.00 [0.57, 1.75]
Rassweiler (2003)	22/219	19/219		12.86	1.16 [0.65, 2.08]
Roumeguere (2003)	9/56	10/52		10.79	0.84 [0.37, 1.89]
Remzi (2005)	8/41	6/39		9.57	1.27 [0.48, 3.32]
Remzi (2005)	8/41	5/41		9.05	1.60 [0.57, 4.48]
Touijier (2008)	56/222	100/193		15.30	0.49 [0.37, 0.63]
Total (95% CI)	923	1047		100.00	0.87 [0.54, 1.39]

Total events: 147 (RRP), 209 (LRP)
Test for heterogeneity: Chi^2 = 35.59, df = 8
(P < .0001), I^2 = 77.5%
Test for overall effect: Z = 0.59 (P = .56)



RR, relative risk.
A

First-day urine loss ratio	Continence			
	Continence time			
	Early continent	Midterm continent	Late continent	Incontinence
0–0.049 (n = 339)	303 (89.4%)	29 (8.5%)	3 (0.9%)	4 (1.2%)
0.05–0.149 (n = 313)	230 (73.5%)	49 (18.9%)	8 (2.5%)	16 (5.1%)
0.15–1 (n = 287)	122 (42.5%)	85 (29.6%)	22 (7.7%)	58 (20.2%)

B

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CHAPTER 91

Robot-Assisted Radical Prostatectomy

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Introduction

The first successful laparoscopic nephrectomy was performed in June 1990 by Clayman *et al.*, and it not only revolutionized the management of renal tumors, but galvanized the minimally invasive surgery movement in urology [1]. Lead by some of the very same pioneers, the initial description of a transperitoneal laparoscopic radical prostatectomy (LRP) was reported in 1992 in abstract form at the annual meeting of the American Urological Association (AUA) [2]. This initial case series was published several years later [3]; however, due in large part to the difficult reconstruction of the vesicourethral anastomosis and the lack of demonstrable patient benefit, the authors did not recommend the routine adoption of this technique. In the very same journal issue, Raboy *et al.* published their initial experience with an extraperitoneal approach to LRP, but also concluded that, although encouraging, further evaluation and refinements were necessary [4].

Despite tepid support in North America, by the late 1990s, the technique had made its way to a handful of centers in Europe. In 1998 the group at the Institut Mutualiste Montsouris in Paris, led by Drs Vallencien and Guillonneau, reported their initial experience with LRP after having completed almost 30 cases using a new antegrade approach [5]. Based on their initial results, these authors felt that LRP could be reasonably performed by a well-trained team, with comparable oncologic outcomes and perhaps improved functional outcomes. Although groups led by Dr Abbou in France [6] and Dr Rassweiler in Germany [7] reported similar early experiences with LRP, with the exception of a few centers in the USA, the technique largely remained in Europe.

Technically challenging, ergonomically demanding, and of debatable benefit over the traditional open retropubic radical prostatectomy (RRP), LRP was neither accepted nor adopted for routine application by mainstream urology in North America. This was in part due to the fact that, while laparoscopy was quickly adopted and applied in Europe, there were few laparoscopic centers of excellence in the USA at that time. These laparoscopic experts in Europe were more readily able to overcome the learning curve of LRP and perform some of the more technically challenging aspects of LRP, such as the vesicourethral anastomosis, while experienced open but laparoscopically naïve surgeons in the USA had difficulty.

In 2001, several groups in Europe introduced the urologic community to the da Vinci Surgical System® (Intuitive Surgical, Sunnyvale, CA, USA) with their initial reports of robot-assisted laparoscopic radical prostatectomy (RARP) [8–10], a technology initially applied in the cardiac surgery field [9, 10]. The following year, the first report of a large series of RARPs performed in the USA was published by Menon *et al.* at the Vattikuti Urology Institute in Detroit, Michigan, USA [11].

Initially described as "telepresence surgery," the da Vinci robot provided surgeons with a more ergonomic surgical platform in addition to increased instrument

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dexterity and precision, hand tremor filtration, and improved three-dimensional vision. Despite a lack of long-term oncologic data, and initially buoyed in part by a combination of patient demand and marketability, RARP has grown in a geometric fashion over the last decade. In 2007, it was estimated that over 60% of all radical prostatectomies performed in the USA were done using the da Vinci robotic platform. This represented a growth of approximately 50% over the previous year, when only about two of every five radical prostatectomies performed were done so using the RARP technique. Extrapolating from this trajectory, some have estimated that by 2010, nearly 80% of all radical prostatectomies performed in the USA will have been done so using the da Vinci robot [12].

The learning curve

The learning curve associated with RARP has been shown to be much more accommodating than that of LRP, if by nothing else but the simple fact that more urologists have successfully incorporated this technology into their practices than have LRP. Studies have demonstrated that proficiency in LRP can be achieved after 40–100 cases in the hands of experienced laparoscopic experts [13, 14]. However, the RARP learning curve may be as low as 10–20 cases, based on operative times, for even the laparoscopically naïve surgeon [15, 16]. It should be mentioned, however, that the learning curve for RARP, as with any new innovative surgical technique, is dichotomous in nature. The "technical" learning curve is significantly different from the "outcomes" learning curve, a concept that has been raised by those interested in seeing the safe and effective application of this technology [17]. Although a safe RARP may be performed efficiently (i.e. within an acceptable operative duration), the ability to effectively achieve oncologic and functional outcomes similar to those of open radical prostatectomy may take significantly longer. As Herrel and Smith have reported, the learning curve to reduce positive surgical margins to a level comparable to open radical prostatectomy may take upwards of 150–250 cases [18].Careful patient selection, however, can help reduce the slope of the early learning curve associated with the adoption of this procedure. Table 91.1 delineates some of the patient and disease factors that should be avoided during this early learning curve. The surgeon should be especially cognizant of the challenges of large prostates and obese patients. Large prostates, generally defined as greater than 50 cm^3 on ultrasound, are a challenge due to the confines of the bony pelvis. A caveat that should be considered is that transrectal ultrasound typically underestimates prostate weight by 20% [19]. For similar reasons, in an obese patient with a fatty bladder and/or rectosigmoid colon that restricts the working space, vision and ease of dissection can be dramatically impaired.

Table 91.1 Patient and disease features to avoid during initial learning curve.

Prior history of abdominal or inguinal surgery
Prior history of prostatitis, prostate surgery (e.g. transurethral resection or microwave thermotherapy of the prostate, etc) or prostate radiotherapy
Large prostates (>60 g)
Body mass index >30
Features suggestive of a narrow pelvis
Evidence of a large median lobe
High preoperative erectile function [e.g. five-item International Index of Erectile Function (IIEF-5) score >21]
Patients requiring pelvic lymphadenectomy

Perioperative care issues

In order to ensure both safety and efficiency in the operating room, patient positioning should be a process that involves every member of the surgical team. The anesthesiologist should be made aware of the steep Trendelenburg positioning that will be required and some of the nuances of maintaining a patient in this position for long periods of time.

The nursing team should be able to facilitate the swift and safe preparation and docking of the patient cart. A detailed description of patient preparation and operating room set-up is provided in Chapter 68 (Figure 91.1).

The patient is initially placed in the supine position, with arms tucked and padded at their side. The use of shoulder rests should be avoided as this can lead to serious brachial plexus injury. The legs can either be placed on spreader bars and gently separated or placed in padded boot stirrups in a low lithotomy position. The primary complication to avoid is hyperextension of the femoral nerve when using spreader bars and careful padding of the posterior knee to prevent nerve impingement when using stirrups. The legs are lowered slightly to facilitate docking of the robot and after placing the patient in steep Trendelenburg, a Mayo stand should be placed over the patient's head and shoulders without interfering with the anesthesiologist's access to the endotracheal tube. This serves to protect the patient's face from the instruments and camera when they are being changed or cleaned, as well as to provide a place to rest the assistant's arm. A 16 or 18F Foley catheter is inserted after the sterile drapes have been placed. It has been demonstrated that catheters of 22F or greater can

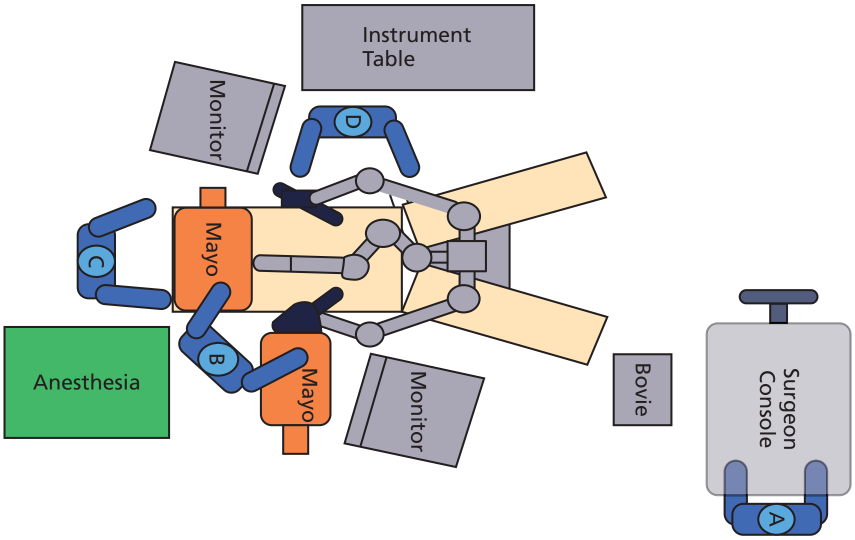

Figure 91.1 Operating room set-up for robot-assisted radical prostatectomy.

be associated with nearly a 10% risk of fossa navicularis strictures [20].

Corneal abrasions, although infrequent, are considered to occur secondary to positional eye edema. When patients awaken, the edema irritates the eyes and they inadvertently rub and scratch their eyes, resulting in corneal abrasion. Foam-based safety goggles should be placed over the patient's eyes for about 90 min in the recovery room, until the patient is fully alert and oriented enough not to rub their eyes.

A multimodal approach to postoperative pain management is employed with avoidance of narcotics as much as possible. Unless otherwise contraindicated, patients are started on ketorolac as the wounds are being sutured, but always prior to extubation. We aim to have the patient pain free when they awaken in the postanesthesia recovery room. Patients are discharged from the hospital on postoperative day (POD) 1 and have prescriptions for ibuprofen and acetaminophen if needed. We find that about 80% of patients are off pain medications by POD 4. We avoid narcotics because although they may control pain well, the resulting constipation leads to prolonged bloating and prolonged need for pain medication.

Thigh-high external pneumatic compression devices are used both during surgery and in the postoperative period as part of routine antithromboembolic care. Early ambulation protocols beginning the evening of surgery are also implemented; we ask patients to walk as much as one half mile on POD 1. Using this protocol we have not seen either deep vein thrombosis or pulmonary embolism in more than 750 consecutive patients.

As a rule, urethral catheters are routinely removed on POD 7 without cystography, except for those rare cases when patients continue to experience hematuria or a complicated bladder neck reconstruction was required.

Pneumoperitoneum and trocar placement

A detailed description of the basic principles of gaining access into the peritoneum, establishing pneumoperitoneum, and trocar placement are outlined in Chapters 70, 74, and 75. As such, only a brief discussion of the finer points of trocar placement specifically for RARP follows.

The recommended distance between all robotic trocar sites is approximately 10 cm. This allows for maximal range of motion with minimum clashing of robotic arms. With the standard da Vinci robot, the arms have a maximum working length of 25 cm. As demonstrated by Pick *et al.*, instrument ports should thus be placed no further than 18 cm from the pubic symphysis to ensure the arms can reach the necessary depth of the working field [21]. With the newer da Vinci S and Si robots, this limitation on working length is no longer a significant issue.

With the newer four-arm robotic systems, six ports are placed for the procedure: one camera port, three robotic ports, and two assistant ports (Figure 91.2). The camera is usually placed above the umbilicus through a 12-mm port inserted using a blunt-tipped trocar, although other descriptions have the port placed lateral to or below the umbilicus. A transverse curvilinear incision at the perimeter of the umbilical crease is employed as this provides for better cosmesis at the skin level and a stronger fascial closure. Recent analysis of outcomes data from our institution has demonstrated the physical

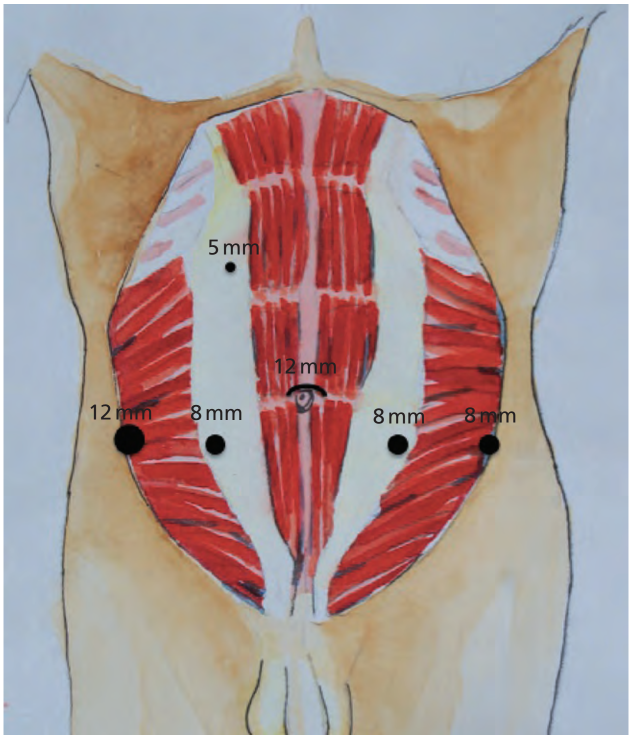

Figure 91.2 Port placement for robot-assisted radical prostatectomy

benefits of this transverse incision, as opposed to the traditional vertical midline incision [22].

The other ports are placed, as outlined in Figure 91.2, under direct vision. The robotic fourth arm port can be placed on either the patient's right or left side, which is mainly dictated by surgeon preference and the surgical assistant's hand dominance. For left-hand dominant assistants, it is preferable to have the assistant sit at the patient's right and as such, this port should be placed on the patient's left side. For right-hand dominant assistants, it is preferable to have them sit on the patient's left side with the robotic fourth arm port on the patient's right.

Several different instrument combinations have been described for use during RARP and choice is mainly based on surgeon training and preference. Most surgeons will use a long-tipped or ProGrasp™ forceps for the fourth arm and a bipolar Maryland or PK™ dissecting forceps for the left arm. As for the right arm, while some prefer to use a monopolar hook or monopolar flat spatula, we prefer a pair of monopolar scissors.

Operative technical steps

General approach

The majority of RARP surgeons utilize a transperitoneal approach, although some have advocated an extraperitoneal approach [23–25], citing decreased risks of bowel injury and postoperative ileus as some of the advantages [23, 26]. In addition, institutional differences exist as to whether to take an anterior approach [17, 27, 28] or a posterior approach to the seminal vesicles, as described initially by the group from Montsouris [13]. Others have also debated the differences between an ascending, retrograde dissection versus a descending, antegrade dissection [8, 11, 14, 29], or even some combination of the two as is performed in open RRP [9, 30].

Understanding that surgeon preference is likely the most significant factor in determining which approach is employed, we prefer a transperitoneal, anterior approach with antegrade dissection. This approach allows for optimal visualization during dissection of the neurovascular bundles (NVBs). Using the principle of triangulation, dissection in the caudal direction provides for better visualization of the structures being dissected, as compared to trying to see around the bulky prostate and dissecting back towards the bladder. It also allows the surgeon to perform the often difficult apical dissection after mobility of the prostate has been established. Finally, the antegrade approach also allows the surgeon to better identify and preserve the NVBs, owing to the fact that the vascular pedicles to the prostate are a consistent landmark that aid in the reliable identification of the interfascial plane between the prostatic capsule and NVB.

Anterior bladder mobilization and retraction suture

After successful placement of all trocars and confirmation that all instruments are in working order, using a 0° laparoscope, an inverted "U"-shaped incision is made in the anterior peritoneum from one inguinal ring to the other, with the base of the "U" placed close to the umbilicus across both medial umbilical ligaments. The arms of the "U"-shaped incision should be carried down to the inguinal ring until the crossing vas deferens is identified, thus allowing for adequate mobilization of this bladder-containing "flap." Through a combination of blunt dissection and electrocautery, the space of Retzius is entered and the bladder is "dropped" from the anterior abdominal wall, exposing the pelvic side wall and the posterior aspects of the pubic symphysis and pubic crest. Care should be taken not to traumatize the pelvic bone as this can result in meddlesome bleeding that can often be difficult to control.

Once the bladder is fully mobilized, we recommend a full-length 3-0 monocryl retraction suture be placed at the top of the urachus and be brought out through the 5-mm assistant port found in the right upper quadrant of the abdomen. This cephalad retraction suture takes 2–3 min to place and pulls the bladder and rectosigmoid colon out of the pelvis, significantly improving exposure and working space, thereby freeing the fourth arm or assistant. It also serves to protect both the large and small bowel from inadvertent upstream thermal injury as the bladder "flap" separates all instruments from the bowel (see Video 91.1).

The fatty tissue overlying the prostate is removed in order to improve visualization of the puboprostatic ligaments, dorsal vein, and anterior bladder neck. Although not routinely performed at all institutions, we believe that this maneuver facilitates the apical dissection and reduces the risk of anterior apical positive margins. This will be discussed in further detail later in the chapter. Invariably, the superficial branch of the dorsal venous complex (DVC) is encountered during this step and is cauterized and divided. After the fatty tissue is dissected off the prostate, it is further dissected off the bladder and then submitted for pathologic examination. Technically, there is no reason to leave the fatty tissue attached to the bladder and removing it gives better visualization of the anterior bladder neck. Furthermore, the lateral limits of this fatty tissue are in direct anatomic continuation with region 3 of an extended pelvic lymph node dissection. As reported by Finley *et al.*, this anterior prostatic fat contains lymph nodes in up to 15% of cases, resulting in potential pathologic upstaging in 2–3% [31] (see Video 91.2).

Control of dorsal venous complex and apical dissection

After the endopelvic fascia is incised with cold scissors, the prostate is mobilized laterally down to the membranous urethra, sweeping the levator muscle fibers off the prostate with little to no cautery used. Care must be taken not to avulse the occasional perforating vessels, particularly closer to the apex, where they are more commonly found. Owing to the improved visualization of the da Vinci robot, the surgeon is then able to safely divide the puboprostatic ligaments and sweep away the overlying levator fibers found adherent to the DVC without encountering problematic bleeding. This detailed dissection is made possible by the 12x magnification of the working field and the removal of all anterior prostatic fat as described earlier, ultimately allowing for an increased length of DVC to be exposed. Subsequently a more distal ligation of the DVC is possible, facilitating a more precise dissection of the prostatic apex. Borin *et al.* demonstrated that dissecting and transecting the urethra an extra 3–6 mm distally resulted in no significant change in time to continence or overall continence rates, while decreasing apical positive surgical margin rates from 13% to 5.5% [32]. It is important to note that positive apical margins occur because of transection too close to the apical prostate.

Once adequate exposure has been obtained, it is our preference to use a 45-mm endoscopic stapler with a vascular staple load to ligate and divide the DVC. After the stapler has been engaged around the DVC, it is essential to maintain clamping for 60 s prior to firing the stapler. This ensures a more secure staple line by compressing all edema and vascularity out of the tissues. As described in the original publications of RARP, suture ligation remains the most popular method of controlling the DVC [10, 11, 27, 28]. However, we prefer the consistent and reproducible effect of stapling as it reliably gives a visual landmark to transect the urethra, hence reducing positive apical surgical margins (see Video 91.3).

Bladder neck transection

This is the most common part of the procedure with which inexperienced surgeons struggle. There are a number of reasons for this, but most prominent we believe is the absence of obvious visual landmarks, the innate natural anatomic variability of the junction, and the need to "feel" the difference between the prostate and the muscle of the bladder. After the camera is switched to the 30° down scope, we first identify the posterolateral contour of the prostate. Next it helps to see or "feel" the prostatovesical junction by compressing or pinching the bladder at its junction with the prostate. The prostate will result in minimal excursion of tissue, while compression of the bladder wall will be evidenced by an obvious mobility in the tissue. In and out traction on the Foley balloon also aids in identifying the anterior bladder neck.

Using the principles of traction and counter-traction to aid in defining the detrusor muscle fibers, electrocautery is used to divide the abundance of arteries and veins that traverse this region. However, muscle in and of itself will not bleed and can be cut "cold." We prefer to fully transect the anterior and posterior bladder neck muscle with scissors, reserving monopolar cautery (set at 25–35 W) for when vessels are encountered. Once the anterior bladder is opened down to the urethra in the midline, the Foley catheter is identified and deflated. The catheter tip is delivered into the surgical field and the robotic fourth arm grasps the Foley through its eyelet and pulls it anteriorly towards the abdominal wall. Counter-traction is provided by clamping the outer portion of the Foley catheter to the surgical drapes. This provides anterior retraction of the prostate off the posterior lying structures and also serves to prevent CO_2 leakage through the catheter. The bladder neck is then dismembered from the prostate using a bladder neck-sparing technique; however, it is important to open the bladder neck adequately to visualize the trigone and assist in defining the angle of transection of the posterior bladder neck. Sometimes the bladder attaches with a gentle slope and at other times the trigone may approach the prostate at a 90° angle. The posterior bladder neck can be divided directly, trying to avoid inadvertent entry into the posterior prostate. It is our preference to approach the bladder neck laterally, entering the space between the posterior bladder wall and the seminal vesicles. The dissection starts laterally where some of the anterior vascular pedicle is still present. With cautery the vessels are transected. Again, the muscle is cut cold, which allows the dissection to proceed behind the posterior bladder neck into the space anterior to the vasa and seminal vesicles. As in open surgery, the surgeon must always be mindful of dissecting into the ureteral orifices proximally and the prostate gland distally.

Posterior dissection

As mentioned earlier, the Montsouris technique involves initial dissection through the pouch of Douglas to dissect the seminal vesicles off the rectum posteriorly and the bladder anteriorly. This dissection can be carried through Denonvilliers' fascia down to the apex of the prostate. If this approach has been taken, the transection of the posterior bladder neck will lead directly into this previously dissected plane. A theoretical disadvantage to this approach is that all sympathetic nerves coursing from the hypogastric autonomic plexus, between the lateral tips of the seminal vesicles and the bladder neck, are divided. As experience would dictate from retroperitoneal lymph node dissections for testis cancer, there is substantial innervation of the bladder neck in this area. All testis cancer surgeons are aware of the complication of retrograde ejaculation due to an incompetent bladder neck, which occurs when these nerves are resected.

As we do not perform a posterior dissection at the onset of the procedure, this step is completed after the bladder neck has been fully transected. Posteriorly, the anterior layer of Denonvilliers' fascia is identified and incised transversely to gain access to the ampulla of the vas deferens and the seminal vesicles. Initially, the right or left vasa and seminal vesicles are identified and dissected fully as a unit completely down to the tip of the seminal vesicle. We recommend simple transection of the vas without a locking clip as the clip is not necessary and can migrate into the anastomosis and has been implicated in severe bladder neck contractures. With one vas deferens and seminal vesicle dissected, the robotic fourth arm or surgical assistant uses these structures to provide further anterior traction on the prostate. This facilitates an easier dissection of the vas deferens and seminal vesicle on the contralateral side.

Once the vas deferens and seminal vesicles have been dissected bilaterally, using the robotic fourth arm or the surgical assistant, they are grasped *en bloc* and pulled anteriorly, exposing the posterior aspect of the prostate. After entering the posterior leaf of Denonvilliers' fascia in the midline, and exposing the perirectal fat, the rectum is mobilized off the prostate using a combination of sharp and blunt dissection. This dissection is carried out to the level of the prostatic apex, staying close to the posterior surface of the prostate. It is crucial to carry this dissection far enough distally to completely mobilize the rectum off the prostatic apex, and thereby reduce the chance of rectal injury during the apical dissection and transection of the urethra. Posterior counter-traction of the rectum provided by the surgical assistant facilitates this dissection.

Release of the neurovascular bundles

With the posterior dissection complete, the lateral prostatic vascular pedicles are well exposed as pillar-like structures. There have been several different techniques used to secure vascular control of the pedicles; however, all will agree that a minimal thermal technique is essential in preventing local thermal injury to the nearby NVB. Authors have described the use of locking hemostatic clips [33] or bulldog clamps [34, 35]. We have modified our initial technique using bulldog clamps and now employ lasso-style suture ligation of the vascular pedicles (Figure 91.3). This avoids the need to develop windows in the pedicle for placement of clips, which can often lead to bleeding, as well as the need for an experienced assistant who can place and remove clamps accurately and efficiently (see Video 91.4). Regardless of the technique employed, once the vascular pedicles are ligated, an athermal technique should be used to complete the dissection of the NVB off the prostate. As well demonstrated by Ong *et al.* in the canine model, application of hemostatic energy sources in proximity to the NVB can result in significantly decreased erectile response to cavernous nerve stimulation [36]. We have corroborated these findings in the clinical setting as reported in 2008. In our single surgeon series, comparison of cautery and cautery-free nerve-sparing techniques employed during the first 500 consecutive RARP cases demonstrated an almost five-fold difference in early return of sexual function. At 9 months after surgery, the cautery group was shown to have a potency rate of 14.7%, while the cautery-free group had a potency rate of 69.8% at the same time point. Over time, the cautery group did demonstrate recovery of sexual function; however, the cautery-free group continued to "outperform" in long-term analysis, with a potency rate of 92% (vs 63.2%) at 2 years post-RARP [37].

With the vascular pedicle transected, the interfascial plane between the prostatic capsule and NVB is reliably identified. The prostate is then swept gently off the NVB until it has been released down to the level of the urethra. By completely mobilizing the prostate, the antegrade,

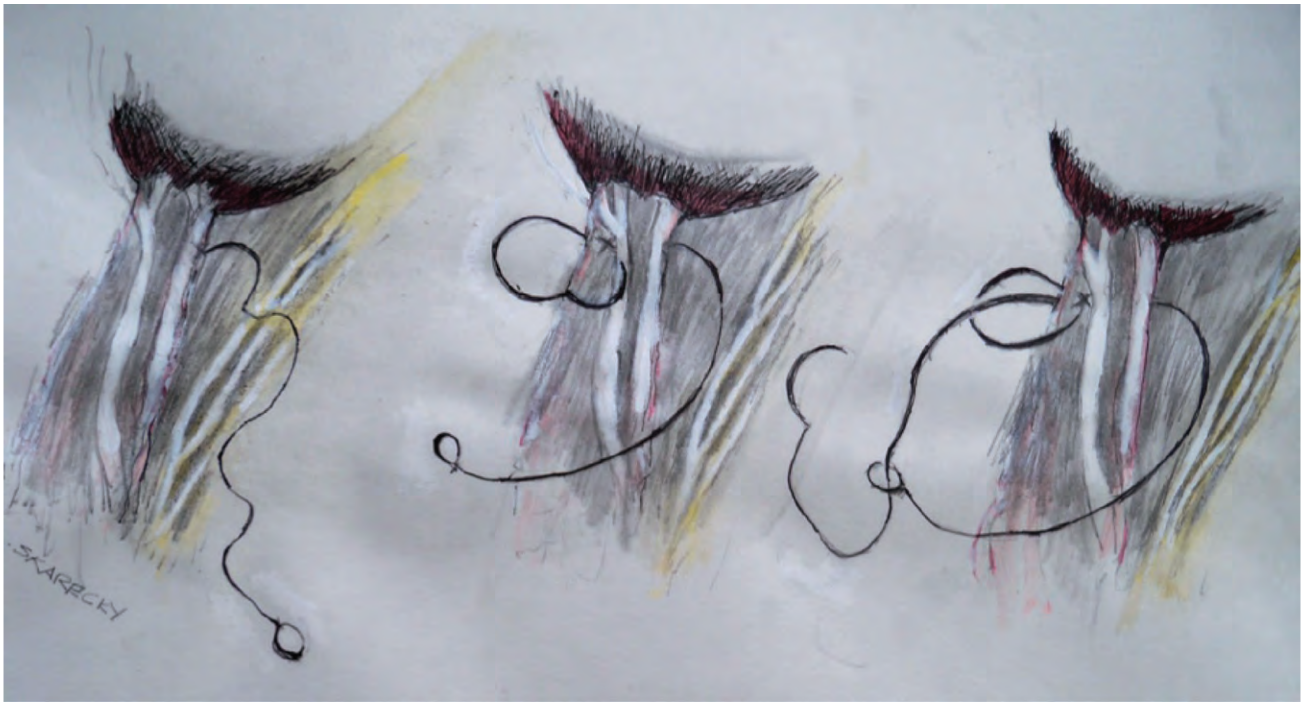

Figure 91.3 Suture ligation of prostatic vascular pedicle.

descending approach allows the surgeon to facilitate the separation of the NVB from the prostatic apex and urethra, an often challenging task.

Since the landmark autopsy study of the pelvic plexus by Walsh and Donker in 1982 [38], the technique of anatomic, nerve-sparing radical prostatectomy has resulted in significant improvements in sexual function outcomes. Since that time, however, several anatomic studies have demonstrated that there may be some variability in the distribution of periprostatic nerves, with nerve tissue being found as high up as the ventrolateral surface of the prostate [39–41]. As such, some authors have advocated a high incision of the lateral prostatic fascia along the ventrolateral aspect of the prostate, leaving what has been described by Menon *et al.* as the "veil of Aphrodite" [42]. The benefits of this high anterior release have not only been shown in RARP but in traditional open RRP as well [43]. However, some have questioned the role of the high anterior release, stating that the anteriorly found nerves mainly innervate the prostate [44–46] with little functional capacity with respect to cavernosal tissue. In addition, these authors claim that improved outcomes from a high anterior release may result from the reduction of traction injury to the posterolaterally placed NVBs. Finally, they also state that the lack of intraoperative electrostimulation studies to corroborate the role of these anterior nerves further questions the impact of high anterior release. Almost as a rebuttal to these arguments, a recent study by Kaiho *et al.* demonstrated that intraoperative electrostimulation at the anterior and lateral borders of the prostate did indeed increase cavernosal pressures [47].

There has also been significant debate as to the impact of an "intrafascial" dissection, as initially described in 2004 [48]. Although some observational studies have reported good erectile function outcomes with this approach [49, 50], others have questioned the benefits of the intrafascial technique [46, 51, 52]. We firmly believe that extensive redundancy exists between the NVBs. Walsh, Catalona, Ahlering and data from the CaPSURE database all demonstrate that if unilateral and bilateral NVB preservation are compared, the improvement in potency rates rises only 1.15–1.35x rather than the anticipated 2x [53–56]. The argument is further supported by the finding that the quality of sexual function recovery as based on five-item International Index of Erectile Function (IIEF-5) scores was identical regardless of number of nerves being spared [55]. Further, redundancy is ubiquitous in nature. Hence, redundancy and logic should dictate that if doubling the volume of nerve preserved increases outcomes by just 25%, then increasing the volume of nerve preserved with an intrafascial approach would only be expected to improve potency by 1–2%. The risk of a positive surgical margin logically speaks against the risk of an intrafascial technique. Recently, Potdevin *et al.* reported that debatable improvement in potency rates may come at the price of oncologic control [57]. We believe an athermal technique with minimization of traction on the NVB serves to accomplish similar outcomes and conforms to the oncologic principles of a radical prostatectomy.

With the NVB completely mobilized, the urethra is transected sharply several millimeters distal to the prostatic apex. The specimen is then placed in a small entrapment sac, and temporarily positioned in the upper abdomen. The purse-string attached to the entrapment sac is removed through the 12-mm assistant port and secured with a small clamp.

The pneumoperitoneum pressure is then reduced and the NVB is examined for hemostasis. Any small arterial bleeders are controlled with the precise placement of absorbable 4-0 suture ligatures. The vascular prostatic pedicles are also examined for hemostasis, with precise placement of absorbable 3-0 suture ligatures for any evidence of bleeding. It is important to remove the retraction suture, suspending the bladder at this point in preparation for the anastomosis.

Urethral anastomosis

In 2001, the initial teams describing RARP all utilized interrupted sutures to perform the vesicourethral anastomosis [9–11], as they had done in their LRP experiences. However, as luck would have it, van Velthoven *et al.* described the use of a single-knot running suture for RARP [58]. Historically, the urethrovesical anastomosis was the most challenging aspect of LRP or RARP, technically speaking. The van Velthoven stitch, as it is now referred to, allowed for 10 needle placements through the bladder and urethra in a tension-free fashion; five throws from each of the two 7-inch monofilament absorbable sutures. The suture is prepared by tying together the tails of two 7-inch monocril sutures on SH or RB-1 needles. As originally described by van Velthoven *et al.*, once both sutures have been placed, the right and left sutures are cinched up from the bladder gently and securely, approximating the posterior lip of the bladder to the posterior urethra [58]. The critical benefit of this technique is that the initial tension of approximating the bladder to the urethra is dispersed over 10 needle holes rather than two with interrupted techniques. It is simple and creates a watertight anastomosis with only one intracorporeal knot required.

A second critical improvement to the reconstruction of the bladder to the urethra is the Rocco stitch first described in 2006 [59]. Much debate exists as to whether it improves time to continence, but we strongly recommend incorporating the stitch as there is universal agreement that it further facilitates a tension-free anastomosis and is very hemostatic. It adds no more than 3–5 min and in our experience more than 98% of men have clear urine 1 day post surgery. In our experience, patient calls regarding clots and hematuria and visits to the clinic or emergency room have been nearly completely eliminated. Lastly, in our experience since incorporating the Rocco stitch, the bladder neck contracture rate appears to be less then 1 in 500 cases. We recommend a 9-inch, 3-0 absorbable monofilament suture to place a continuous, running stitch between the cut edge of Denonvilliers' fascia, with a small bite of posterior bladder wall, and the posterior external striated sphincter found beneath the urethral stump. By cinching this suture, the bladder is secured about 1–2 cm from the urethra.

Next, the van Velthoven suture is passed into the surgical working field. There has been a slight modification from its initial description: instead of starting at the 6 o'clock position with both needles, we start out-to-in on the bladder at the 4 o'clock position with one needle. In this fashion the preformed knot is found outside on the posterior bladder wall. After five throws have been placed in a clockwise direction, the system of loose loops is cinched together in a winch-like fashion to bring the posterior bladder neck in apposition with the posterior urethra. It is important to always cinch on the bladder side to prevent pull-through; tearing is a problem if the fixed and more flimsy urethra is used. Once the posterior aspect of the anastomosis has been pulled water tight, the suture is then continued clockwise to approximately the 10 o'clock position. The suture can then be held tight by the fourth arm. The needle on the right side of the anastomosis is then used in a similar fashion to place a continuous running suture from the 5 o'clock to 11 o'clock position, in a counterclockwise direction. A transition stitch is placed at the 11 o'clock position in order to tie across the anastomosis.

A Foley catheter is used as a suture guide during the placement of the anastomotic suture, with perineal pressure applied as needed to improve exposure of the urethral stump. Once the anastomosis has been completed, an 18F silastic catheter is placed into the bladder and a total of 10 mL of sterile water is used to inflate the catheter balloon. The bladder is then subsequently irrigated through this catheter to confirm proper placement, to remove blood clots, and to visually inspect for any evidence of anastomotic leakage. The definitive urethral catheter may be inserted prior to placement of the final throw of the anastomotic suture to visually confirm proper placement; however, we believe that when done properly, the catheter passes across the anastomosis without any difficulty.

There have been several other descriptions of techniques used to improve functional continence outcomes post radical prostatectomy [33, 60, 61]; however, we feel the Rocco stitch lends itself best to the RARP procedure. It makes the anastomosis technically easier by stabilizing the posterior structures, dramatically reduces postoperative hematuria, and may improve time to continence [59]. We have recently reported on the exciting role of local hypothermia in improving continence outcomes after RARP [62]. Taking well-established lessons from cardiac and neurosurgeons in using cooling techniques to stop the inflammatory cascade common to all trauma, iatrogenic or otherwise, the use of an endorectal cooling balloon allows us to locally cool the pelvic region to approximately 50–68° F. Initial studies not only demonstrate an earlier return to continence, but higher "zero pad" rates at 3 and 12 months post RARP. We continue to perform studies addressing the impact of hypothermia on erectile function and examining the role of different cooling regimens on functional outcomes.

A final hemostatic check of the entire surgical field is performed before undocking the robot and removing the prostate specimen through the umbilical port, the easiest port site to close. Minimal enlargement of the umbilical incision in a transverse direction can facilitate the safe and easy removal of the specimen from the surgical field. The entrapment bag and prostate are inspected prior to transfer to pathology and the fascia is then closed with a looped 0 absorbable suture such as PDS (Ethicon, West Somerville, NJ, USA). The assistant ports and the 8-mm robotic ports are not closed. We do not routinely place a surgical drain at the end of the procedure. Recent literature supports this practice [63, 64]; however, drains may be left at the surgeon's discretion. Absorbable subcuticular sutures, skin staples, and/or a biologic adhesive can be used to close the skin incisions.

Pelvic lymph node dissection

For patients with preoperative oncologic parameters mandating the need for pelvic lymphadenectomy, we recommend an extended pelvic lymph node dissection (PLND), as described by Mattei *et al.* [65] and recently discussed by Briganti *et al.* [66]. A full discussion regarding the indications for, and extent of, pelvic lymphadenectomy is not specific to RARP and is beyond the scope of this chapter. However, even if this debate is disregarded, there remain institutional differences regarding the recommended timing of the PLND during RARP. Although some have described performing the PLND at the start of the procedure [27, 67], we prefer to perform the extended PLND after the prostate has been removed, just prior to the vesicourethral anastomosis. With the prostate removed from the pelvis, there is greater exposure of the vessels, facilitating the extended dissection up to the level of the common iliac vessels. Also, by performing the main oncologic portion of the procedure first, any small risk of having to abort the procedure due to inadvertent major vascular injury during lymphadenectomy is avoided. Finally, due to significant improvements in staging imaging, the likelihood of aborting a RARP due to grossly positive pelvic lymph nodes at the time of surgery is vanishingly rare.

Complications

Complications during RARP are often related to surgeon experience, and as such are more common during the initial learning curve. In addition, during the "acceleration phase" of the learning curve, after the surgeon has become proficient in the basics of the procedure and begins to tackle more difficult cases, a temporary increase in complications may emerge.

There are also several patient factors that may influence the rate of complications during RARP, such as obesity, prostate size, history of prostate surgery, etc. With that said, none of these factors is specific to RARP, and indeed all influence outcomes regardless of the approach. As with open RRP, several studies have demonstrated that obese patients undergoing RARP tend to have significantly longer operative times, greater blood loss, higher complication rates, and perhaps worse oncologic and functional outcomes [68–70]. Patients with larger prostates have also been associated with greater blood loss, longer hospital stays, higher complication rates, and worse functional outcomes [71, 72].

As with reporting of oncologic and functional outcomes, the current published literature with regards to complication rates for RARP suffers from a lack of standardization. Based on a few publications using the standardized Clavien system [73] for reporting surgical complications, RARP was associated with an overall complication rate of 12.2–26%, although only 0.5–8.5% of these were Clavien 3 or greater [74–78]. Blood transfusions were required in approximately 1–5% of patients, while urine leak and bowel injury were seen in 4.5–7.5% and 0.6–1.5%, respectively. Due to the lack of standardization, it is difficult to use the currently published literature to make a direct comparison between RARP and open RRP complication rates.

Intraoperative complications

Intraoperative complications can be classified as either access related or procedure specific. Access-related complications are not specific to robotic surgery but are germane to all laparoscopic procedures. We will limit our discussion to RARP-specific complications.

Rectal injuries most commonly occur during the dissection of the prostatic apex. Regardless of whether the posterior dissection is performed at the very start of the procedure, as described by the group from Montsouris [13], or done following transection of the prostatovesical junction, if not completely mobilized off the posterior aspect of the prostate, the rectum that remains adherent to the apex is at risk of injury during transection of the urethra. Although less common, rectal injuries can also occur during the posterior dissection itself. The key is to use the perirectal fat as a guide to stay in the correct plane, dissecting close to the prostatic surface. Finally, when performing non-nerve-sparing RARPs for aggressive high-risk prostate cancer, lateral rectal injuries may occur while performing wide resection of the NVBs, particularly at the apex.

Ureteric injuries, though uncommon, can occur at several different stages of the procedure. First, when dissecting the posterior aspect of the prostatovesical junction, care must be taken with the ureteral orifices located nearby. The interureteric ridge, also known as Mercier's bar, can be used as a landmark to identify their location. In patients with a large median lobe, identification of the orifices may be difficult for the novice surgeon. As such, we recommend avoiding these types of patients during the early learning curve. The second stage where ureteric injuries may occur is during the anastomosis. Particularly when the posterior wall of the bladder has been somewhat thinned, surgeons tend to take large bites of the posterior wall with their anastomotic suture in the hope of buttressing the thinned wall. It is important to note that the intramural portion of the ureter must not be included in the suture, particularly when the ureteric orifices are found close to the cut edge of the bladder neck. Finally, the ureter can also be injured during the PLND, as it courses over the iliac vessels.

Other intraoperative complications can occur during the PLND, including major vascular injuries and obturator nerve injuries. Although uncommon, these types of complications can lead to significant patient morbidity. They can occur due to inappropriate direct application of electrocautery, inadvertent direct ligation, coupling of energy to another instrument, or sheer force trauma during blunt dissection. In addition, iliac vessels can be injured during uncontrolled, blind robotic instrument insertion or exchange. Despite these potential complications, several studies have demonstrated that PLND can be safely and effectively performed during RARP [79, 80].

Postoperative complications

Early postoperative complications include urinary tract infections, anastomotic urine leaks, hemorrhage, ileus, deep vein thromboembolism, and peritonitis from unrecognized bowel injury.

Studies have demonstrated that RARP, when compared to open RRP, is associated with significantly less blood loss and a lower risk of requiring blood transfusions [81–87]. This is likely a cumulative result of the improved visualization of the DVC afforded by the da Vinci robot, the ability to accurately identify and precisely ligate bleeding vessels, as well as the effects of the pneumoperitoneum tamponading small venous bleeders. Nonetheless, the need for transfusion following RARP is not nil and vigilance is required in the early postoperative period.

Due in part to the lack of standardized reporting, but also related to the fact that many RARP surgeons do not leave a postoperative drain, the true incidence of anastomotic urine leaks is unknown. Based on published literature, however, it is likely to be in the 5% range [74–78].

Although extremely rare, transient femoral nerve palsies related to positioning have been noted [88]. In our single-surgeon series of almost 1000 cases, we have also noted this on rare occasion, and anecdotally note an association with muscular men who have bulky muscle mass in their lower limbs.

As in open surgery, urinary incontinence and erectile dysfunction continue to be the most common and noteworthy late complications following RARP. The multifactorial nature of both these postoperative rates suggests that patient selection plays just as much a role as any technical or surgeon-related factor. A detailed discussion of functional outcomes after RARP follows in Chapter 92. It should be noted, however, that due to a significant lack of standardization in the published literature with regards to the reporting of these outcomes, as well as the limited use of validated instruments to measure the prevalence of these complications, direct comparisons between RARP series, as well as against open RRP series, are difficult and unreliable.

Bladder neck contractures, lymphoceles, inguinal hernias, and port-site hernias have also been reported. Perhaps, in part, a reflection of the slightly lower rates of anastomotic urine leaks, bladder neck contracture rates also seem to be lower following RARP than open RRP [81, 83, 89, 90].

Outcomes

Oncologic outcomes

Above all, RARP remains an oncologic procedure with curative intent. Some authors have been very vociferous in criticizing the early adoption of RARP without long-term oncologic data to support such widespread application. Although this may have held early merit, recent short- and intermediate-term oncologic data point towards comparable outcomes to standard open RRP. There is no doubt that oncologic data are more robust with traditional RRP; however, as demonstrated by several institutions, RARP seems to be establishing its merits as a valid option in the surgical management paradigm of localized prostate cancer.

In a systematic review of comparative studies published in 2008, the authors found no significant between-group differences in overall risk or incidence of positive surgical margins (PSMs) in patients undergoing open RRP, LRP, and RARP [85]. In a single-institution study by Schroeck *et al.*, the authors also found no significant difference in PSM rates between RARP and RRP on both univariate and multivariate analyses [90]. Interestingly, Smith *et al.* published a report in 2007 which demonstrated that RARP was associated with a significantly lower PSM rate than open RRP: 15% and 35%, respectively [91]. Similarly, a systematic review of comparative studies by Ficarra *et al.* noted a significantly lower PSM rate among those undergoing RARP compared to RRP [92].

Some authors have debated the true impact of PSM after prostatectomy, citing biochemical recurrence and disease-specific survival as better oncologic markers. In a large study by Krambeck *et al.*, there was no difference in biochemical progression-free survival at 3 years after RARP and RRP: 92.4% and 92.2%, respectively [93]. Barocas *et al.* demonstrated similar findings in another single-institution comparison of RARP and RRP where the 3-year biochemical recurrence-free survival was 84% and 83.5%, respectively. In this study, the cohort undergoing RRP had higher-risk features; however, on multivariate analysis procedure type was not a significant predictor of biochemical recurrence [94].

Through careful patient selection and rigorous surgical technique, outcomes for RARP can be optimized to maintain the curative intent of this procedure (Table 91.2). As with open surgery, a meticulous dissection in adherence to sound oncologic principles must be ensured, particularly at the apex of the prostate. In addition, the use of preoperative information such as site-specific biopsy results and findings on digital rectal examination to guide the dissection is crucial in achieving this goal.

Functional outcomes

As discussed earlier, the literature is rife with publications reporting on functional outcomes following radical prostatectomy that lack standardization. In addition, many studies employ nonvalidated instruments or questionnaires in measuring continence and erectile dysfunction rates. As an example, it is the authors' firm belief that "0–1 pads" and "one security pad only" is significantly different from "pad-free" continence. To this effect, using patient-administered, validated questionnaires, Liss *et al.* demonstrated that quality-of-life scores decreased significantly between "no pads" and "security pad" or "0–1 pad" [95].

As such, direct comparative analyses and generalizability of data are difficult. That said, the majority of large series published on RARP demonstrate continence and erectile function outcomes comparable to the robust data of open RRP [27, 85, 90, 93]. Interestingly, there are several reports that may suggest an earlier return of continence and sexual function after RARP, which is encouraging [87, 96]. In contradistinction, a highly publicized study by Hu *et al.* reported a significantly higher rate of incontinence (15.9 vs 12.2 per 100 person-years) and erectile dysfunction (26.8 vs 19.2 per 100 person-years) after "minimally-invasive radical prostatectomy." Unfortunately, this study was based on Current Procedural Terminology (CPT) codes only, without the use of any validated instruments, and grouped RARP and LRP together in the analysis [81]. In addition, the two groups were significantly different prior to propensity weighting.

Many different dissection techniques have been described in the literature in attempts to improve functional outcomes following RARP (a more detailed discussion on outcomes can be found in Chapter 92); however, a basic principle can be found among many of these descriptions. Whether through the use of athermal

Table 91.2 Technical tips for robot-assisted radical prostatectomy.

Technique	Rationale
Placement of bladder retraction suture	Improves working space in the pelvis Protects bowel from iatrogenic injury
Removal of anterior prostatic fat	Improves visualization of the dorsal venous complex, allowing for more distal ligation
Antegrade dissection of neurovascular bundles with minimal traction	Reduction of trauma to nerve tissue
Use of van Velthoven suture for vesicourethral anastomosis	Technically easier than interrupted sutures Improved water-tight anastomosis
Transverse umbilical incision to remove prostate specimen	Decreased rate of port-site hernias Improved cosmesis

techniques, the avoidance of excessive traction, seminal vesicle-sparing dissections, or the use of locoregional cooling strategies, the reduction of inflammation and injury to key structures is vital in preserving and optimizing functional outcomes.

For more experienced RARP surgeons who have optimized and standardized their surgical technique, patient factors likely play a larger role in predicting functional outcomes than any specific technical nuance or strategy. Variables such as patient age and preoperative functional status are strong predictors of outcomes. As an example, the five-item International Index of Erectile Function (IIEF-5) score correlates well with postoperative erectile function and likely serves as a strong surrogate marker of overall health and vitality. In addition, although to date there is a relative paucity of literature regarding this issue, the role of serum androgen levels in predicting functional outcomes is an interesting and exciting avenue of research.

Outcomes self-assessment

It is imperative for the robotic surgeon to establish a surgical database of preoperative demographics and postoperative outcomes for critical self-evaluation. Self-assessment is a continual iterative process, and as the volume of cases increases, a personal database allows the surgeon to quickly measure themselves against published results. Through the process of self-assessment of outcomes, the surgeon can decide if there are specific troublesome technical or clinical issues. There are two important self-assessment tools: video recording of cases and rigorous data collection.

Digitally recording each case can be extremely advantageous not only to the novice surgeon but to those with experience as well. Reviewing the operation in realtime is particularly useful for difficult cases, complications, and PSMs. Also, cases with excellent functional outcomes can be reviewed for positive reinforcement of successful techniques. As demonstrated by several groups, a surgeon reviewing video-taped footage of their surgical performance can have a positive impact on improving and evolving their surgical technique [97–100].

Data collection of patient demographics and outcomes is also essential to truly understand the success or failure of robotic surgery. A proposed minimum data collection design is shown in Table 91.3. Preoperative data must be stringently collected as most functional outcomes may be dependent on the baseline characteristics of the patient. Preoperative data also give the surgeon a benchmark, as the ideal goal is to restore all men to preoperative functional status. Postoperative oncologic and functional data, in addition to complication rates, should be meticulously recorded if the surgeon hopes to be critical of their technique and improve surgical performance. In order to determine the true place of robotics in the surgical pantheon, validated questionnaires and analog assessment scales are essential in determining true functional results, and need to be combined with careful long-term follow-up of oncologic outcomes.

Table 91.3 Suggested data collection.

Preoperative
Patient information (age, body mass index, etc.)
Number of positive biopsy cores and location(s)
Clinical stage
Clinical Gleason score
Prostate-specific antigen (PSA) level
Prostate size by transrectal ultrasound
Sexual Health Inventory for Men (SHIM), five-item International Index of Erectile Function (IIEF-5)
Operative
Operating room time
Estimated blood loss
Hospital stay
Complications
Postoperative
Positive surgical margin and location(s)
Pathologic Gleason score
Prostate weight
PSA level/recurrence
SHIM score/IIEF-5
International prostate symptom score (IPSS)/American Urological Association score
Urinary bother score
Daily pad usage for continence/EPIC

The thorny issue of statistical analyses should be explored early through consultations with an expert statistician. This relationship will make the proposed data collection more effective and efficient. As sexual potency and continence outcomes will not be available until 6–12 months into the surgeon's RARP experience, preconsultation with a statistician regarding data collection methods is a strategic and time-saving advantage for any program.

Conclusions

Minimally invasive surgery in urology has come a long way since the initial description of the laparoscopic nephrectomy 20 years ago. Through advances in technology, engineering and science, urologists are now able to offer patients ever more optimized care with minimized morbidity.

The early, widespread adoption and application of RARP into the prostate cancer management paradigm was criticized by some for its lack of substantiating evidence both in safety and effectiveness. However, with the maturation of technology, surgeon skill level, and outcomes data, evidence suggests that not only is RARP a safe option for patients with prostate cancer but perhaps, in certain respects, a more effective one as well.

Looking forward, RARP is a new technology that seems to be here to stay. It is up to robotic surgeons themselves to ensure the safe and effective training in and application of this technology to improve patient outcomes. In addition, it behooves us to employ self-assessment strategies, use validated instruments, and standardize reporting of both outcomes and complications so that we can improve upon current results with this technology. Above all else, it must be kept in mind that in the prostate cancer management decision analysis process, it is the decision to operate that is the key issue, not the incision.

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CHAPTER 92

Optimizing Outcomes During Laparoscopic and Robot-Assisted Radical Prostatectomy: Oncologic Concerns, Potency, and Continence

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Introduction

The initial description of radical prostatectomy dates back to 1905 when Hugh Hampton Young performed the first radical prostatectomy for cancer through a perineal approach. In 1947 Millin was credited with describing a retropubic approach to prostatectomy. At that time, many patients presented with palpable cancers and therefore were not cured by radical prostatectomy alone. They also suffered from severe urinary incontinence and complete impotence. It was not until the late 1970s and early 1980s, when a more anatomic approach to radical retropubic prostatectomy emerged as a result of a greater appreciation of the striated urethral sphincter [1] and neurovascular bundle (NVB) [2], that postoperative continence and potency improved. This was followed by the development of minimally invasive approaches to radical prostatectomy that included laparoscopic prostatectomy (LRP) and robot-assisted laparoscopic prostatectomy (RALP).

LRP was first described in 1996 in a canine model [3]. The first human series was published 1 year later by Schuessler *et al*. [4] and later modified in 2000 [5, 6]. RALP was first described by several centers in Europe in 2001 [7–9] and later popularized in the USA by the work of Menon *et al.* in 2002 [10]. RALP and LRP have maintained the oncologic and functional outcomes of open surgery, but with a reduction in blood loss, transfusion rates, and postoperative convalescence [11]. The vast majority of radical prostatectomies in the USA are now performed using a minimally invasive approach.

The implementation of prostate cancer screening with the use of prostate-specific antigen (PSA) testing in the late 1980s resulted in the detection of cancers more likely to be confined to the prostate gland, and therefore more likely to be cured by prostatectomy. This has led to increased focus and attention on functional outcomes after radical prostatectomy. Accordingly, the quest for the perfect "trifecta" of cancer cure and preservation of complete continence and potency has caused several groups to review their experience and outcomes with radical prostatectomy. Bianco *et al.* reported on 1746 patients who underwent open radical retropubic prostatectomy with a mean follow-up period of 6 years. Although 83% of the men had effective cancer control, only 60% attained the perfect trifecta after 2 years following surgery as most were affected by erectile dysfunction [12]. Shikanov *et al*. in 2009 reviewed 380 patients who underwent RALP. They reported that only 44% of patients achieved the perfect trifecta at 2-year follow-up according to strict definitions of functional outcomes based upon validated quality-of-life surveys [13].

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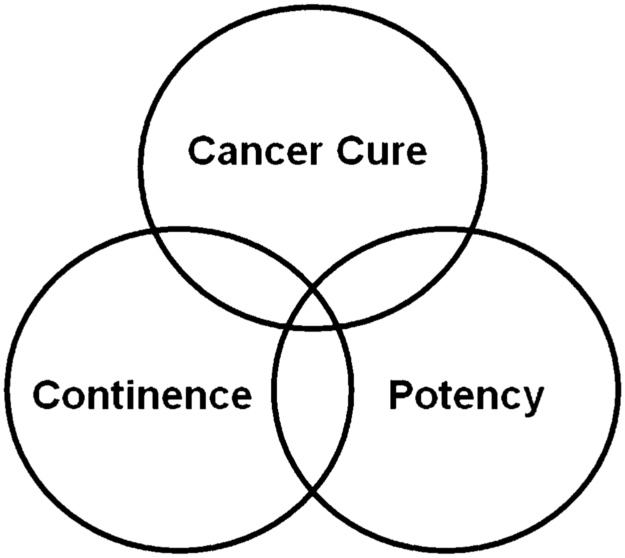

Figure 92.1 The "trifecta": competing goals of radical prostatectomy.

The three postprostatectomy outcomes of cancer cure, urinary continence, and potency are in reality competing goals, where optimization of one outcome may come at the expense of another (Figure 92.1). Furthermore, the possibility of the perfect trifecta may not be realistically achieved in all men due to factors related to the extent and aggressiveness of the cancer, including PSA, volume, grade, and stage of disease. For example, cancers with more aggressive features may warrant a more extensive local surgical excision (i.e. wide excision) to eradicate all cancer, which may concurrently jeopardize the functional outcomes of continence and especially potency.

As a result of the enhanced visual perspective of surgical anatomy with LRP and RALP, there have been many investigations revisiting the neuroanatomy involved in penile erections and the support mechanisms involved in urinary continence. In turn, surgical modifications to RALP and LRP have been introduced over the last decade to optimize both oncologic and functional outcomes, which also appear to improve the trifecta outcomes, particularly after RALP [14]. These concepts will be the subject of this chapter.

Optimizing oncologic outcomes

Surgical margin status and biochemical recurrence have generally been relied upon as surrogates for oncologic efficacy following radical prostatectomy. Multiple factors can influence positive surgical margin rates, including grade and stage of disease, surgeon experience, pathologic analysis, and surgical approach. The most significant factor that determines the positive margin rate in a given series is patient selection. Use of prediction tools and nomograms has allowed for risk stratification and better selection of patients who have organ-confined cancers and thus are more likely to benefit from surgery [15–17]. For example, patients with very high-risk disease can be informed that surgery or radiation alone may not be sufficient and that a multimodality approach to treating their particular cancer may be required. On the other hand, patients with low-volume and -grade disease are at lower risk and are therefore more likely to be cured with a greater likelihood of preservation of quality of life.

Surgeon experience has been identified by some to have a strong association with surgical margin status [18]. Inherent in a surgeon's evolving experience with prostatectomy is their willingness to critically evaluate and track positive surgical margin rates and address potential causes and technical modifications for improvement. To this end, stage-stratified margin rates can provide a surgeon with critical information as to which positive margins may be attributable to technical error (i.e. pT2 disease) as opposed to the aggressiveness of disease (i.e. ≥pT3 disease). Moreover, site-specific positive margins can provide important insights as to the effect of cavernous nerve preservation, bladder neck preservation, and maximization of functional urethral length on posterolateral, bladder neck, and apical margins, respectively. Table 92.1 summarizes the stage-specific positive margin rates for LRP and RALP. In most series, the positive margin percentages decrease with greater experience and familiarity with the procedure.

Surgical technique during both laparoscopic and radical prostatectomy can also influence positive surgical margins at site-specific locations, including the apex, bladder neck, and posterolateral border of the prostate.

Prostatic apex

The prostatic apex is the most common site of positive surgical margins in most reported series. LRP and RALP both allow excellent apical visualization of the prostate to facilitate a meticulous dissection. By fully exposing the prostatic apex after dividing the puboprostatic ligaments, the deep dorsal venous complex (DVC) can be either suture ligated or stapled close to the pubis and well away from the prostatic apex. This reduces the chance of an iatrogenic positive surgical margin from occurring when a surgeon divides the dorsal vein. In cases where the puboprostatic ligaments are not sufficiently divided, the dorsal vein suture or staple line may end up too close to the prostatic apex. As a result, the surgeon may divide the dorsal vein too close to the prostatic apex in attempts to avoid cutting the previously placed suture. This may result in iatrogenic entry

Table 92.1 Reported pT2 and pT3 stage-specific positive margin rates for laparoscopic radical prostatectomy and robot-assisted laparoscopic prostatectomy.

Series	Total patients	Positive margins (%)	
		pT2	pT3
Laparoscopic radical prostatectomy series			
Hoznek *et al.* (2002)	250	16.4	39.3
Guillonneau *et al.* (2003)	1000	15.5	31.1
Roumeguere *et al.* (2003)	85	18.4	45.7
Su *et al.* (2004)	177	4.7	44.8
Rozet *et al.* (2005)	599	14.6	25.6
Rassweiler *et al.* (2005)	500	7.4	31.8
Lein *et al.* (2006)	1000	14.8	21.1
Stolzenburg *et al.* (2008)	2000	9.7	33.9
Hakimi *et al.* (2009)	75	12.7	25
Robot-assisted laparoscopic prostatectomy series			
Wolfram *et al.* (2003)	81	12.7	42
Ahlering *et al.* (2004)	140	12.3	48.8
Cathelineau *et al.* (2004)	105	11.7	43
Atug *et al.* (2006)	140	18.1	53.8
Joseph *et al.* (2006)	325	9.9	32.7
Zorn *et al.* (2007)	300	15.1	52.1
Smith *et al.* (2007)	200	9.4	50
Badani *et al.* (2007)	2766	13	35
Mottrie *et al.* (2007)	184	2.6	37.1
Patel *et al.* (2008)	1500	4	34
Hakimi *et al.* (2009)	75	10.9	18
Shikanov *et al.* (2009)	703	12	51
Murphy *et al.* (2009)	400	9.6	42.3
Patel *et al.* (2010)	404	7.0	42

into the prostate apex with a capsular incision, or worse still, leave residual prostate tissue on the dorsal vein stump. Ahlering *et al.* noted in their series a significant decline in T2-positive margins from 27% to 4.7% ($P = .003$) with modifications to apical preparation, including division of the puboprostatic ligaments followed by stapling of the DVC [19]. It is also important to note that considerable variation exists in the shape and contour of the prostatic apex [20, 21]. Protrusion of the prostatic apex beneath the urethra is a unique anatomic variation that warrants special consideration. In such cases, the posterior lip of the prostatic apex develops asymmetric to the anterior apex and thus protrudes beneath the urethra. When dividing the prostatourethral junction, it is important to anticipate this anatomic variation so as not to divide the urethra flush with the prostatic apex and leave residual posterior apical prostate tissue behind. Instead, a more tangential resection is required in such cases so as to ensure complete excision of the posterior prostatic apical tissue.

Bladder neck

Patients with high-volume tumors located at the base of the prostate may be at higher risk of bladder neck involvement. In such cases, wider excision of the bladder neck (i.e. nonbladder neck-sparing procedure) may be prudent to decrease the risk of a positive bladder neck margin. Although wide excision at the bladder neck may in theory compromise the time to recovery of postoperative urinary continence, simple closure of the redundant bladder neck opening in conjunction with modifications to the support of the vesicourethral anastomosis (as described in more detail in the section on Optimizing urinary continence outcomes below) have led to excellent continence rates.

Posterolateral margin and neurovascular bundles

Perhaps the most challenging technical step of prostatectomy lies within the intent to eradicate all cancer while preserving the NVBs for the sake of preserving postoperative erectile function. Recent enthusiasm for more "aggressive" preservation of the NVBs (as discussed in the section on Optimizing potency outcomes) has been noted by some groups to be associated with an increase in positive surgical margins as a result of closer dissection along the prostate surface [22]. The prediction of extracapsular extension of cancer along the posterolateral border of the prostate can be challenging, especially in the era of PSA screen-detected cancers where microscopic and multifocal disease are more commonly encountered as compared to palpable cancers. As such, the relative unpredictability of location and focality of tumor presence makes intraoperative decision-making challenging, especially during the steps of NVB preservation. Furthermore, the lack of haptic feedback with current laparoscopic and robotic technology and the loss of the ability to palpate the prostate surface and detect areas of induration may in theory compromise the ability of a surgeon to adjust the plane of dissection to avoid an iatrogenic positive margin. In efforts to address these issue, Satake *et al.* recently reported on their nomogram for predicting extracapsular extension based upon standard clinical factors (clinical stage, serum PSA, highest Gleason score) and biopsy features (such as maximum percent of cancer in the biopsy cores), concluding that these parameters could help accurately identify which patients are most suitable to undergo cavernous nerve preservation [23]. In addition to risk stratification, we advocate performing a thorough digital rectal examination with the patient fully anesthetized at the beginning of the operation and before initiating LRP or RALP, in order to gain incremental information as to the presence (or absence) of palpable disease along the posterolateral border of the prostate.

In the end, having a thorough appreciation of each individual patient's unique anatomic nuances and challenges will allow a surgeon to optimize cancer control, while preserving urinary and sexual function in the quest for the perfect "trifecta" [21].

Optimizing potency outcomes

Technical modifications to optimize potency outcomes for LRP and RALP depend on an accurate understanding of the anatomic distribution of the cavernous nerves responsible for penile erection. Walsh and Donker are credited with the initial discovery of nerve fibers that run adjacent to the prostate gland to the penile bodies [2]. The discovery of these extraprostatic nerve bundles would later prove to contain the cavernous nerves responsible for penile erection. In 1998, Walsh published his findings from dissections in stillborn male infants and step-section, whole mount adult cadaveric studies of the autonomic innervation to the bladder and prostate. This would eventually lead to the current surgical approach of anatomic nerve-sparing prostatectomy which aims to preserve the delicate postganglionic parasympathetic fibers of the cavernous nerves [24]. However, several important studies published between 2004 and 2005 have since shown greater complexity to the anatomic distribution of the cavernous nerves than previously thought [25–27]. These studies demonstrated that the periprostatic nerves appear to be more diffuse and variable than initially thought, and include accessory nerve branches that travel along the anterolateral border of the prostate within the periprostatic fascia (Figure 92.2).

These neuroanatomic studies have led to changes in the approach to nerve-sparing prostatectomy, which attempt to increase both *quantitative* and *qualitative* nerve preservation. A modification addressing improved *quantitative* preservation of the cavernous nerves involves incising the levator fascia along the anteromedial portion of the prostate rather than the traditional posterolateral location (Figure 92.2). A plane is then created and extended in a posterolateral direction along the prostatic fascia, extending from the base of the seminal vesicles toward the apex of the prostate. This technical modification attempts to preserve a broad sheet of neurovascular and periprostatic tissue, which should include any accessory nerves that take a more anterior course in addition to the cavernous nerves

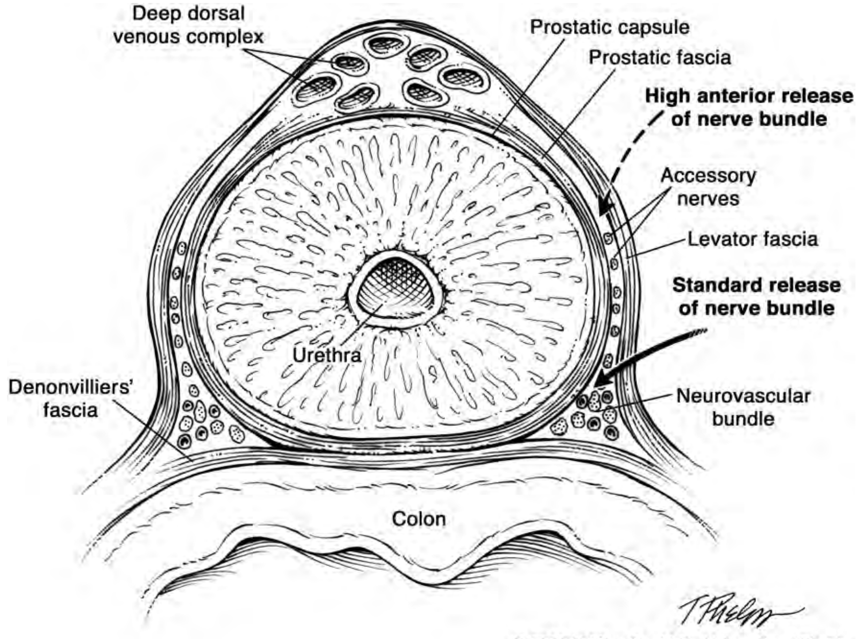

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Figure 92.2 Anatomic relationship of the neurovascular bundle (NVB) and accessory nerves to the periprostatic fascia. A high anterior release of the NVB is performed by incising the levator fascia along the anteromedial border of the prostate as opposed to the standard posterolateral release of the NVB along the posterolateral surface of the prostate.

traveling within the traditional NVB, thus leading to an increased *quantitative* nerve preservation. However, it should be noted that the relative contribution, if any, of these accessory nerve fibers to penile erection remains controversial [26]. Several terms have been used to describe this modification including the "veil of Aphrodite" [27], "curtain dissection" [28], and "high anterior release of the levator fascia" [29].

Studies evaluating the effect of increased *quantitative* nerve preservation are limited, with some showing improved potency when compared to conventional cavernous nerve preservation. In 2005, Menon *et al*. compared their "veil of Aphrodite" technique to conventional nerve preservation during RALP [30]. At 12 months, 97% of patients receiving the "veil of Aphrodite" nerve preservation reported successful intercourse versus 74% of men receiving the standard nerve-sparing procedure ($P = .002$). The same group later used an S-100 nerve stain to evaluate the number of nerves remaining within the periprostatic fascia of the surgical specimens. In the conventional group, a mean of 10 nerve bundles were identified compared to only two bundles in the "veil of Aphrodite" group, suggesting that more periprostatic nerves remained *in situ* in the "veil" group [31], where greater potency outcomes were observed. This study suggests that preserving a greater number of nerves that travel within the anterolateral periprostatic fascia leads to greater postoperative potency.

Nielsen *et al*. also studied cavernous nerve preservation using a similar dissection termed the "high anterior release" of the levator fascia. They evaluated postoperative potency using the Sexual Health Inventory for Men (SHIM). Patients undergoing high anterior release were more likely to achieve a SHIM score of 16 or greater at 1 year after radical prostatectomy when compared to the traditional nerve-sparing technique (93% vs 77%, $P = .007$) [29]. Percent return to baseline in patients with SHIM scores of greater than 21 was also greater in the high anterior release group among patients who were sexually active (78% vs 52%, $P < .05$). This improved outcome in potency did not increase the likelihood of a positive surgical margin. In their discussion, Nielson *et al*. postulated that the high anterior release of the periprostatic fascia served to better define the posterolateral prostatic plane for improved, tension-free preservation of the conventional NVB, rather than contributing itself to quantitative nerve preservation. Lastly, it should be noted that others have reported no improvement in potency when comparing a high, intrafascial nerve dissection (curtain dissection) to the conventional dissection of the NVB in a series of 310 LRP patients (potency defined as SHIM > 11; 68.4% vs 67.2% at 1 year, $P = 1.0$) [32].

The quantity of cavernous nerves preserved during prostatectomy is also dependent upon the plane of dissection used during nerve preservation and whether an *extra*fascial, *inter*fascial or *intra*fascial approach is used. Extrafascial dissection represents a wider excision around the prostate gland, maintaining all layers of periprostatic fascia covering the prostate. This technique involves complete excision of the NVB and is utilized in patients in whom a higher risk of extracapsular extension of tumor along the posterolateral surface of the prostate is suspected. During interfascial dissection of the NVB, a plane is developed between the levator fascia and prostatic fascia, and represents the recommended plane of dissection used during conventional preservation of the NVB (Figure 92.3). Lastly, an intrafascial dissection involves releasing the NVBs one layer closer to the prostate by dissecting between the prostatic fascia and the prostatic capsule in order to further optimize cavernous nerve preservation. This dissection, however, should be used selectively in patients with low-volume and low-grade tumors as closer dissection to the prostate capsule may risk an increased rate of positive surgical margins. Potdevin *et al.* compared an athermal intrafascial nerve-sparing robotic prostatectomy to a conventional interfascial nerve-sparing robotic prostatectomy. While the intrafascial group was more potent at 9 months (91% vs 67%, $P < 0.01$), the pT3 positive surgical margin rates were almost double (41% vs 22%, $P < .05$) [22]. This was later supported in a study incorporating extraperitoneal/endoscopic (RALP and LRP) radical prostatectomies that randomized patients to inter- versus intra-fascial nerve dissection. The intrafascial group was again more potent at 12 months (83% vs 65%, $P = .005$), while the pT3 positive surgical margin rates were also higher in the intrafascial group, though statistical significance was not reached (32% vs 26%) [33]. In surgical practice, however, intraoperative findings, such as suspicious appearance of tissue or adhesions adjacent to the NVB, may warrant deviation from the anatomic dissection along these periprostatic fascial planes. In such cases, partial or "incremental" nerve preservation in the regions of concern can be performed to avoid complete and wide excision of the entire NVB. In support of this, a study by Levinson *et al.* noted that a surgeon's subjective characterization of the relative quantity of nerves preserved correlated with objective postoperative recovery of potency [34]. In the end, surgeon experience and judgment guided by clinical parameters such as digital rectal examination (i.e. clinical stage), tumor volume and location, grade, PSA, and intraoperative findings should be used collectively to determine the optimal plane of cavernous nerve preservation to optimize potency outcomes without jeopardizing cancer cure [17, 23]. Table 92.2 summarizes the reported potency outcomes after LRP and RALP.

In addition to a focus on the *quantitative* aspect of preservation of the NVB during prostatectomy, greater

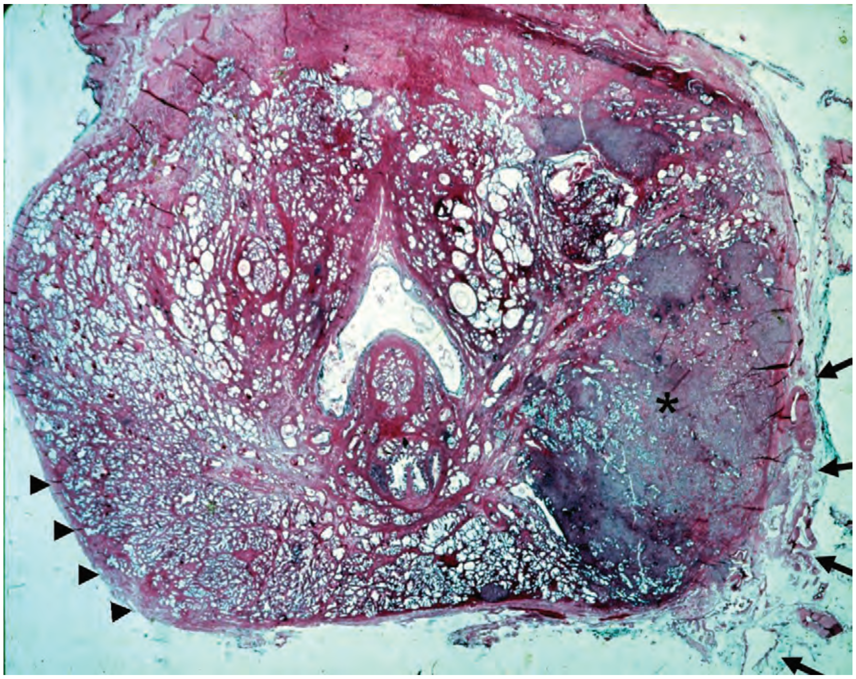

Figure 92.3 Whole-mount section of a prostatectomy specimen demonstrating the difference between an interfascial (left side) and extrafascial dissection (right side) of the neurovascular bundles (NVBs). Note the high-volume cancer (*) on the right lobe closely approximating the NVB, which has been excised along with the prostate by an extrafascial dissection (arrows). In contrast, no NVB remains on the left posterolateral surface of the prostate where interfascial dissection was performed with preservation of the NVB (arrowheads).

emphasis has also been placed on improving the *quality* of the nerve preservation. *Qualitative* nerve preservation relates to the handling of the NVB during dissection with emphasis to avoid stretch and thermal injury. The use of extensive thermal energy during LRP and RALP prompted Ong *et al.* to study the effect of thermal injury on cavernous nerve function in a canine model. They found that all forms of thermal energy, including ultrasonic shears, and bipolar and monopolar electrocautery, caused injury to the sensitive postganglionic parasympathetic fibers of the canine cavernous nerves [35]. This was demonstrated by an absolute reduction in the magnitude of stimulated erections, with no further recovery noted 2 weeks following cavernous nerve thermal injury. These findings were supported in a human study by Ahlering *et al.* using a cautery-free nerve-sparing technique that showed greater early potency rates at 3 months when compared to dissection using bipolar electrocautery (47% vs 8.3%, $P < .001$) [36]. However, in a follow-up study, the same group reported that the thermal and cautery-free groups showed no significant difference in potency at 2 years, suggesting that the insult to the cavernous nerves may be due to neuropraxia rather than permanent injury [37]. As a result, the effect of thermal injury on cavernous nerve function has led to the adoption of an "athermal" approach to nerve preservation in order to maximize early return of postprostatectomy potency.

Erectile function is impaired following radical prostatectomy even after the most meticulous nerve-sparing dissection. Some degree of neuropraxia is unavoidable because of the close proximity of the NVB to the prostate gland. The recovery of the cavernous nerves is very slow and may take as long as 3 years before baseline function is reached [38]. Meanwhile, a lack of erections leads to a series of events which can culminate in tissue hypoxia and apoptosis with a resultant decrease in penile size and cavernosal fibrosis. This has led to the concept of postprostatectomy penile rehabilitation to enhance penile vascularity and integrity of the corporal tissues with the hope of maximizing postoperative recovery of erections.

The pathophysiology of postprostatectomy erectile dysfunction is multifactorial and has been elucidated in both animal and human models [39]. Initial postoperative neuropraxia leads to a lack of erections, which leads to decreased blood flow and poor oxygenation to the corporal bodies. This diminished penile blood flow is further compounded by a reduction in arterial inflow to the penis after ligation of accessory internal pudendal arteries during prostatectomy. This leads to hypoxia within the penis, which sets off a cascade within

Table 92.2 Reported potency outcomes in laparoscopic radical prostatectomy and robot-assisted laparoscopic prostatectomy.

Series	Evaluable patients	% BNS	Mean age (years)	Method of assessment	Definition used	Follow-up (months)	Potency rate (%)
Laparoscopic radical prostatectomy series							
Hoznek *et al.* (2001)	82	32	64.8	Questionnaire	Intercourse	1	46
Turk *et al.* (2001)	44	11	59.9	Physician	Intercourse	12	59
Salomon *et al.* (2002)	43	39.5	63.8	Questionnaire	Intercourse	12	58.8
Eden *et al.* (2002)	100	58	62.2	Physician	No pads	12	62
Guillonneau *et al.* (2002)	47	N/A	N/A	Physician	Intercourse	1.5	66
Katz *et al.* (2002)	143	44	63	Questionnaire	Erections	12	87.5
Anastasiadis *et al.* (2003)	230	33.5	64.1	Questionnaire	Intercourse	12	53
Roumeguere *et al.* (2003)	85	30.9	62.5	Questionnaire	Intercourse	12	65.3
Su *et al.* (2004)	177	51.4	57.8	Questionnaire	Intercourse	12	76
Rassweiler *et al.* (2004)	109	37.6	64	Questionnaire	Intercourse	12	67
Rozet *et al.* (2005)	231	60.2	N/A	Questionnaire	Intercourse	6	64
Stolzenburg *et al.* (2005)	185	10.1	63.4	Questionnaire	Intercourse	6	47
Wagner *et al.* (2006)	220	66	58	Questionnaire	Intercourse	12	72
Rassweiler *et al.* (2006)	N/A	N/A	64	Questionnaire	Intercourse	12	52.5
Goeman *et al.* (2006)	N/A	N/A	62.4	Questionnaire	Intercourse	12	56
Novara *et al.* (2010)	242	N/A	61.3	Questionnaire	IIEF-6 (>17)	12	89
Ploussard *et al.* (2010)	740	61.8	62.1	Questionnaire	Intercourse	12 24	34.7 64.6
Robot-assisted laparoscopic prostatectomy series							
Menon *et al.* (2003)	200	N/A	59.9	Questionnaire	Intercourse	6	64
Joseph *et al.* (2006)	325	86	60	Questionnaire	IEEF-5 (22–25)	6	68
Zorn *et al.* (2007)	161	100	59.4	Questionnaire	Intercourse	12	80
Patel *et al.* (2007)	200	N/A	63.2	Questionnaire	Intercourse	12	78
Menon *et al.* (2007)	875	N/A	60.2	Questionnaire	Intercourse	12	85
Potdevin *et al.* (2009)*	48	100	58.6	Questionnaire	Intercourse	9	66.7
Potdevin *et al.* (2009)[+]	33	100	58.6	Questionnaire	Intercourse	9	90.9
Ploussard *et al.* (2009)	181	73.8	63.3	Questionnaire	Intercourse	12	39.1
Murphy *et al.* (2009)	232	69.9	60.2	Questionnaire	Intercourse	12	62
Patel *et al.* (2010)	177	100	58	Questionnaire	Intercourse	12	91.5

*Interfascial

[+] Intrafascial

BNS, bilateral nerve sparing; IIEF, International Index of Erectile Function.

corporal smooth muscle cells resulting in apoptosis, muscular constriction, and deposition of collagen resulting in fibrosis and venous leak. The goal of postprostatectomy penile rehabilitation is to stimulate the penile erectile tissues, increase tissue oxygenation within the cavernosal bodies, and decrease fibrosis and apoptosis to improve postoperative recovery of normal erectile function. The impact of penile rehabilitation has been very encouraging in the animal model, but has yet to be replicated in clinical studies where short follow-up and poor patient compliance is prevalent. One encouraging study from Mulhall *et al*. suggests that delaying post-prostatectomy penile rehabilitation beyond 6 months is associated with poorer potency outcomes at 2 years when compared to patients who start penile rehabilitation early (sildenafil-assisted functional erections 45% vs 86%, $P < .01$) [40]. The ideal combination of rehabilitation strategies remains controversial, but early and aggressive penile rehabilitation has become standard practice for many urologists in treating patients who have undergone radical prostatectomy. Although a general consensus has been supported by many andrologists in the field that penile rehabilitation is beneficial, there still remains insufficient evidence as to the precise timing, duration, and ideal rehabilitation protocol, whether it be the use of phosphodiaesterase-5 inhibitors, vacuum erection devices, intraurethral or intracavernosal therapies, or a combination thereof [41].

Optimizing urinary continence outcomes

Urinary incontinence represents a major factor affecting daily quality of life after radical prostatectomy. As a result, there have been continued efforts to refine and modify the surgical technique to restore the vesicourethral anastomosis as close to the presurgical state as possible. Table 92.3 summarizes the reported continence outcomes after LRP and RALP.

Reconstruction of the vesicourethral anastomosis has been compartmentalized to posterior and anterior support. The primary maneuver to reinforce the posterior aspect of the vesicourethral anastomosis was first described by Rocco *et al*. in 2006, who reapproximated the urethral sphincteric complex with an absorbable suture by joining posterior detrusor muscle to remnant Denonvilliers' fascia and then to the posterior median raphe of the rhabdosphincter (Figure 92.4) [42]. As a result of prostatectomy, there is a foreshortening of the urethral sphincteric complex with resultant caudal prolapse and loss of posterior fixation of the rhabdosphincter. The "Rocco stitch" is thought to facilitate continence by re-establishing posterior anatomic support to the bladder and urethra during voiding, increasing the functional length of the rhabdosphincter, and reducing tension on the vesicourethral anastomosis. The Rocco stitch also enhances the vesicourethral anastomosis by improving access and visualization to the urethral stump by reducing caudal migration of the urethra during suturing of the vesicourethral anastomosis. This is particularly advantageous during LRP and RALP where the reapproximation of the urethra and bladder neck is performed under direct visualization. Additional theoretical benefits of this stitch include tamponade and reduction of venous bleeding along the bed of the prostate, and prevention of anastomotic disruption in the event of a pelvic hematoma. This modification to the posterior support of the anastomosis was originally applied to open radical retropubic prostatectomy and resulted in an earlier return to continence when compared to a standard anastomosis without reconstruction. At 3, 30, and 90 days after Foley catheter removal, Rocco *et al.* reported continence rates of 72%, 79%, and 86% compared to 14%, 30%, and 46% in the standard prostatectomy group ($P < .001$). Interestingly, at 360 days, the continence rates between the two groups were not significantly different (95% vs 90%, $P > .05$), suggesting that the Rocco stitch may promote an earlier return to continence rather than improving overall long-term continence rates [42].

Reinforcement of the anterior support of the vesicourethral anastomosis has also been described for RALP [43]. This involves resuspension of the anterior anastomosis and distal bladder neck to the arcus tendineus with the goal of restoring anterior urethral support with preservation of the vesicourethral angle. The technique of joining the anterior and posterior reconstructions (modified Rocco stitch) was termed the "total reconstruction of the vesicourethral junction" by Tewari *et al.* who compared the total reconstruction method during robotic prostatectomy to patients receiving no reconstruction or anterior reconstruction only. In this study, continence was defined as using no pads or just one liner a day for security. The median time to continence for patients undergoing total reconstruction was 3 weeks, with a continence rate of 97% at 24 weeks. The percentage of continent patients in the total reconstruction group was significantly greater at all time points when compared to patients with no reconstruction or anterior reconstruction only (97.1% vs 62.0% vs 85.7%, respectively, at 24 weeks, $P < .001$)). In contrast, Menon *et al.* found no significant benefit from their combined anterior and posterior reconstruction in a prospective, randomized controlled study when compared to patients without any reconstruction [44]. Their continence rates after more than 3000 robotic prostatectomies using 0–1-pad and zero-pad continence criteria were 80% vs 74% ($P > 0.1$) and 42% vs 47% ($P > 0.1$), respectively. Despite these results, Menon *et al*. continue to perform reconstruction of the vesicourethral anastomosis as they have

Table 92.3 Reported urinary outcomes for laparoscopic radical prostatectomy and robot-assisted laparoscopic prostatectomy.

Series	Total patients	Mean age (years)	Method of assessment	Definition used	Follow-up (months)	Continence rate (%)
Laparoscopic radical prostatectomy series						
Hoznek *et al.* (2001)	200	64.8	Questionnaire	No pads	12	86
Turk *et al.* (2001)	125	59.9	Physician	0–1 pads	9	92
Olsson *et al.* (2001)	228	65.2	Questionnaire	No pads	12	78.4
Salomon *et al.* (2002)	235	63.8	Questionnaire	No pads	12	90
Eden *et al.* (2002)	100	62.2	Physician	No pads	12	90
Guillonneau *et al.* (2002)	550	N/A	Physician	No pads	12	82.3
Anastasiadis *et al.* (2003)	230	64.1	Questionnaire	No pads	12	71.6
Rassweiler *et al.* (2004)	500	64	Questionnaire	No pads	12	83.6
Rozet *et al.* (2005)	600	N/A	Questionnaire	No pads	12	84
Stolzenburg *et al.* (2005)	700	63.4	Questionnaire	No pads	12	92
Rassweiler *et al.* (2006)	5824	64	Questionnaire	No pads	12	84.9
Goeman *et al.* (2006)	550	62.4	Questionnaire	No pads	12	82.9
Hakimi *et al.* (2009)	67	59.6	Questionnaire	No leak	12	89.3
Novara *et al.* (2010)	242	61.3	Questionnaire	No leak	12	89
Ploussard *et al.* (2010)	911	62.1	Questionnaire	0–1 pads	12	97.4
Robot-assisted laparoscopic prostatectomy series						
Menon *et al.* (2003)	100	60	Physician	0–1 pads	6	92
Patel *et al.* (2005)	200	59.5	Questionnaire	No pads	12	98
Joseph *et al.* (2006)	325	60	Unknown	No pads	6	96
Zorn *et al.* (2007)	300	59.4	Questionnaire	No leak	12	90
Menon *et al.* (2007)	2652	60.2	Questionnaire	0–1 pads	12	95.2
Patel *et al.* (2007)	500	63.2	Questionnaire	No pads	12	97
Mottrie *et al.* (2007)	184	62	Physician	0–1 pads	6	95
Potdevin *et al.* (2009)	147	58.6	Questionnaire	No pads	6	93.2
Ploussard *et al.* (2009)	206	63.3	Questionnaire	No pads	12	74.1
Ploussard *et al.* (2009)	206	63.3	Questionnaire	0–1 pads	12	98.0
Murphy *et al.* (2009)	400	60.2	Questionnaire	0–1 pads	12	91.4
Hakmi *et al.* (2009)	70	59.8	Questionnaire	No leak	12	93.3
Patel *et al.* (2010)	192	58	Questionnaire	No pads	12	97.4

noted a benefit in reducing urinary extravasation detected on routine postoperative cystogram studies.

In addition to reconstruction of the vesicourethral anastomosis, reconstruction of the bladder neck has also been described as a means of improving postoperative continence rates. In 2002, Walsh described intussusception of the bladder neck by the placement of two figure-of-eight sutures within the perivesical tissue, one posteriorly and the other anteriorly, both of which are located 1–2 cm proximal to the bladder neck [45]. This bladder neck intussusception technique is believed to create a “collar” of perivesical tissue surrounding the bladder neck, which serves to increase bladder neck resistance and prevent passive opening (and thus incompetence) of the bladder neck during bladder filling. In Walsh and Marschke’s study, patients with

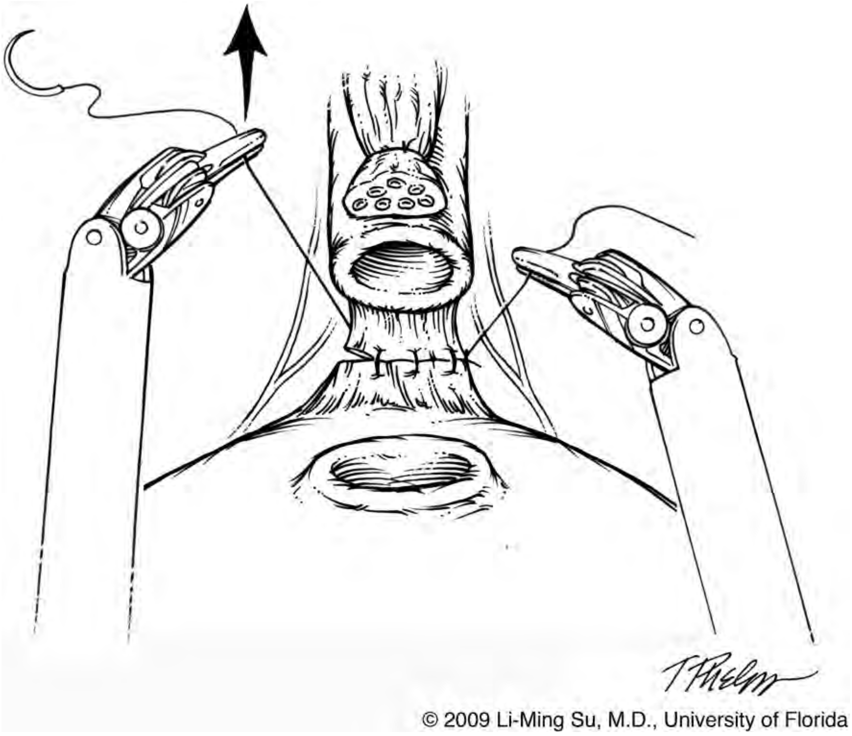

Figure 92.4 Modified Rocco stitch. The posterior rhabdosphincter, remnant Denonvilliers' fascia, and posterior detrusor layers are reapproximated with a running absorbable suture prior to the vesicourethral anastomosis.

intussuscepted bladder necks had significantly improved urinary control at 3 months (82% vs 54% in the control group, *P* = .0035) [45]. A second prospective study confirmed an earlier return to urinary continence at 3 months with intussusception of the bladder neck, though continence rates at 12 months were not significantly different when compared to the control group [46]. A modified version of Walsh's bladder neck reconstruction using just the anterior intussusception stitch has been described and incorporated into laparoscopic and robotic prostatectomy [47]. Further studies are necessary to evaluate the contribution of bladder neck intussusception to recovery of postprostatectomy continence following prostatectomy.

Early return of postprostatectomy continence has also been associated with cavernous nerve preservation [48, 49]. Wei *et al.* reported that median recovery time to complete continence was shorter after nerve-sparing prostatectomy (5.3 months vs 10.9 months, *P* < .01). They reported that while nerve preservation during prostatectomy may help retain autonomic and/or motor innervation to the rhabdosphincter, the surgical technique of sparing the NVB may also help decrease iatrogenic mechanical injury to the rhabdosphincter by avoiding unnecessary tension or traction [48]. Early continence rates after RALP have even shown improvement when comparing intrafascial versus interfascial nerve-sparing prostatectomy at 3 months (68.6% vs 27.3%, *P* < 0.01) and 6 months (68.8% vs 84.3%, *P* < 0.01), suggesting the possible importance of preserving the NVB in early recovery of postprostatectomy continence [22]. However, at 9 months there was no significant difference in continence rates between the groups in this study.

A novel and experimental concept recently described to improve postprostatectomy incontinence involves induction of hypothermia during nerve-sparing prostatectomy [50]. The idea behind induced hypothermia of the prostate bed is to reduce the inflammation and damage of surrounding neuromuscular tissues that may have a detrimental effect on urinary incontinence. This concept of hypothermia to reduce nerve injury caused by surgery or metabolic injury is not new and has been previously reported in the neurosurgical and cardiac literature [51]. Finley *et al*. incorporated the use of an endorectal cooling balloon system to their robotic prostatectomy to induce local hypothermia (mean of 26°C) to the prostatic bed. They reported a higher zero-pad continence rate with hypothermia at 3 and 12 months versus controls (89% and 100% vs 65% and 89%, *P* < .0054) [50]. While the effects of hypothermia on postoperative erectile function are still unknown and further studies are needed to validate the use of hypothermia, these and other concepts may lead to further insights on how to maximize functional outcomes during radical prostatectomy.

Urinary continence rates after prostatectomy may also be improved with postoperative pelvic floor muscle rehabilitation. Postprostatectomy incontinence typically results from dysfunction of the urethral sphincter after striated muscle injury or damage to the innervating nerve fibers, though bladder dysfunction also likely contributes to postoperative incontinence. Pelvic floor muscle rehabilitation is intended to strengthen pelvic floor musculature that supports and closes the voluntary sphincter muscle and to facilitate improved bladder control. A recent updated report in the Cochrane Database of Systematic Reviews evaluated the role of pelvic floor exercises on the reduction of incontinence after radical prostatectomy [52]. There were seven randomized studies available for review; however, heterogeneity in the patient populations, study designs, therapeutic techniques, and definitions of continence precluded meta-analysis. The trials provided conflicting results and the Cochrane review could not conclude on a beneficial effect of pelvic floor exercises. The highest success rate reported for postprostatectomy pelvic floor rehabilitation showed that 88% of men were continent at 3 months versus 56% in the placebo group ($P < .001$) [53]. However, this is yet to be substantiated by further well-designed studies, which will be necessary to make definitive recommendations on the value of postoperative pelvic floor therapy.

Conclusions

The "trifecta" of cancer cure and complete preservation of urinary continence and potency represents the ultimate goal in radical prostatectomy. Unfortunately, achieving the "trifecta" occurs less than 100% of the time and cannot be achieved in all patients due to the extent of their disease, medical comorbidities, baseline characteristics, anatomy, and surgical technique. Technical advances have been made with LRP and RALP in efforts to optimize both oncologic and functional outcomes. However, in the end, it is important to counsel patients based upon their individual circumstances and clinical presentation, and provide realistic expectations in view of each individual surgeon's experience and outcomes.

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CHAPTER 93

Minimally Invasive Simple Prostatectomy

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Introduction

Benign prostatic hyperplasia (BPH) affects approximately 70% of men aged over 70 years and is a significant cause of morbidity for those with BPH and a prostate weight of 60 g or more [1, 2]. The treatment options for bladder outlet obstruction (BOO) caused by BPH have expanded over the past two decades with the development of medical and minimally invasive therapies. For patients with acute urinary retention, persistent or recurrent urinary tract infection, refractory hematuria, severe urinary symptoms, or renal insufficiency, either transurethral resection of the prostate (TURP) or simple prostatectomy are indicated. In general, prostate glands larger than 70–100 g are better managed by open prostatectomy [3].

Open simple prostatectomy can be performed by a retropubic or suprapubic approach. The retropubic approach was popularized by Millin in 1945, and achieves enucleation of the prostate adenoma through a direct incision of the anterior prostatic capsule [4]. Suprapubic prostatectomy, or transvesical prostatectomy, consists of the enucleation of the hyperplastic adenoma through an extraperitoneal incision of the lower abdominal wall, and was popularized by Freyer in 1912, when he reported the results of his first 1000 patients [5].

As with many other urologic procedures, many centers have explored different techniques using a laparoscopic, and more recently, a robot-assisted and single-port approach. For many surgical indications, a robotic or laparoscopic approach translates into less postoperative pain, faster convalescence, fewer wound complications, and improved cosmesis. In 2002, Mariano *et al*. first reported using a laparoscopic approach for simple prostatectomy performed in a patient with BPH [6]. In that case report, a longitudinal vesicocapsular incision was performed to extract a 120-g prostate using four hemostatic sutures for vascular control [6]. Since that time, numerous other case reports and surgical series of laparoscopic simple prostatectomy have been reported [7–15]. Two series of robot-assisted simple prostatectomy have recently been published [16, 17], and single-site and single-port simple prostatectomies have also been reported [18–21].

Surgical techniques and outcomes (Table 93.1)

Laparoscopic prostatectomy

Since the first case of laparosopic prostatectomy was reported in 2002 [6], numerous other surgical series have been published. Most surgeons employ a retropubic (Millin's) approach, and both extraperitoneal and transperitoneal approaches are used. In addition, a finger-assisted technique is occasionally utilized [12, 15].

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Table 93.1 Minimally invasive simple prostatectomy series.

Series	Approach	Cases	Mean EBL (mL)	Operative time (min)	Mean adenoma weight (g)	Hospital stay (days)	Number of conversions to open (%)
Laparoscopic							
van Velthoven *et al.* [8]	Retropubic	18	192	145	48	6	0
Mariano *et al.* [11]	Retropubic	60	331	138	131 (68–398)	3 (2–7)	0
Hoepffner *et al.* [15]	Retropubic*	100	250	66	68 (41–124)	4 (2–10)	0
Sotelo *et al.* [10]	Retropubic	17	516	156	72 (32–120)	2 (1–5)	0
Porpiglia *et al.* [23]	Retropubic	20	411	107	71 (50–103)	8 (6–21)	0
Baumert *et al.* [24]	Multiple[§]	17	367	115	77	5	0
Zhou *et al.* [12]	Retropubic[†]	45	360	105	78 (65–115)	6	0
McCullough *et al.* [22]	Retropubic*	96	350	95	Not reported	6	0
Robot assisted							
Yuh *et al.* [16]	Retropubic	3	558	211	301 (66–640)	1 (1–2)	0
Sotelo *et al.* [17]	Transvesical	7	298	205	50 (40–65)	1 (1–2)	0
Single port							
Desai *et al.* [18]	Transvesical	3	500	200	107 (45–212)	2 (1–3)	1 (33)
Desai *et al.* [21]	Transvesical	34	460	116	68 (17–212)	3 (1–10)	4 (13)

*Finger-assisted approach.

[§] Retropubic (n = 17) and transvesical (n = 13) approach.

[†] Five patients received index finger enucleation.

EBL, estimated blood loss.

In 2004, van Velthoven *et al.* reported on 19 patients who underwent laparoscopic extraperitoneal prostatectomy. Sotelo *et al.* reported their initial experience in 2005 on 17 patients who underwent laparoscopic retropubic simple prostatectomy: mean operative time of 156 min, estimated blood loss (EBL) of 516 mL, hospital stay of 2 days, and adenoma weight of 72 g (range 32–120 g). Three patients (19%) had postoperative complications [10]. In 2006, Mariano *et al*. followed up their initial case report by reporting on 60 patients who underwent laparoscopic simple prostatectomy. In their series, mean age was 69 years, surgical time was 138 min, EBL was 331 mL, and length of stay was 3 days. No patient required open conversion in their series [11]. They reported a significant improvement in maximum flow rate (Qmax) and International Prostate Score Symptoms (IPSS) [11]. Hoepffner *et al*. described a finger-assisted laparoscopic retropubic prostatectomy in 100 patients. At a mean follow-up of 14 months, all men had an IPSS score less than 5 and the mean Qmax was 26 mL/s. They advocated a finger-assisted approach over a pure laparoscopic approach given the shorter operative times and decreased wear on the laparoscopic instruments [15].

In 2009, McCullough *et al*. reported outcomes of 96 patients who underwent laparoscopic transcapsular simple finger-assisted prostatectomy as part of a comparative study with open simple prostatectomy. With their technique, an index finger is used to bluntly dissect the adenoma as in the open technique. The finger is inserted through the suprapubic trocar site [22]. Among the patients who underwent the laparoscopic approach, they reported a mean operative time of 95 min, EBL of 350 mL, and hospital stay of 6 days. Adenoma weight was not reported. Zhou *et al*. reported on 45 patients who underwent extraperitoneal laparoscopic retropubic prostatectomy, with five receiving index finger enucleation. They reported a mean EBL of 350 mL, surgical time of 105 min, postoperative stay of 6 days, and adenoma weight of 78 g (range 65–115 g) [12].

Robot assisted prostatectomy (Table 93.2)

The robotic system offers the surgeon several advantages over standard laparoscopy, including three-dimensional vision, six degrees of freedom in the instrument's movement, and downscaling of movements [3]. To date, two surgical series have been published on robot-assisted simple prostatectomy [16, 17]. At Roswell Park Cancer Institute (RPCI), we prefer to utilize the retropubic (Millin's) approach. The patient is placed in a steep Trendelenberg position and pneumoperitoneum is obtained via a Veress needle. A camera (12-mm) port is placed at the umbilicus with two robotic arm (8-mm) ports placed on the right and the left side. We place a right assistant side (12-mm) port in the right lower quadrant, a few centimeters above the anterior superior iliac spine. The fourth arm (8 mm) is placed on the left side and provides traction to aid with surgical

Table 93.2 Surgical steps for robot-assisted retropubic simple prostatectomy.

Surgical step	Lens	Right robotic instrument	Left robotic instrument	Fourth robotic arm	Assistant port
Incision of the peritoneum and entry into the space of Retzius	0° binocular lens	Hook cautery	Cardiere forceps	Cobra grasper	Microfrance grasper
Prostate capsulotomy	0° binocular lens	Hook cautery	Cardiere forceps	Cobra grasper	Suction
Dissection of adenoma	0° binocular lens	Hook cautery	Cardiere forceps	Cobra grasper	Suction
Apical dissection	0° binocular lens	Monopolar scissor	Cardiere forceps	Cobra grasper	Suction
Posterior mucosal advancement (3-0 Monocryl)	0° binocular lens	Needle driver	Needle driver	Cobra grasper	Laparoscopic scissor
Closure of the capsulotomy (2-0 Vicryl)	0° binocular lens	Needle driver	Needle driver	Cobra grasper	Laparoscopic scissor

exposure. A final 5-mm suction port is placed between the right robotic port and the camera port.

The posterior peritoneum is incised lateral to the umbilical ligament and the bladder is released from the anterior abdominal wall. The bladder is retracted using a grasper through the fourth arm. We make a transverse capsulotomy using electrocautery, and the adenoma is bluntly separated from the capsule using a grasper and the blunt side of the monopolar hook. Circumferential dissection is performed to free the adenoma from the prostatic capsule. We employ sharp dissection at the apex to avoid thermal injury to the external urethral sphincter. The prostatic fossa is then inspected and hemostatis is obtained. We approximate the posterior bladder neck mucosa to the posterior aspect of the prostatic capsule to prevent bladder neck contracture. After passing a urethral catheter into the bladder, the capsulotomy is closed transversely using a running 2-0 Vicryl suture. A suprapubic tube and/or JP drain can be placed at the surgeon's discretion.

Using this approach, we performed robot-assisted retropubic simple prostatectomy on three patients. The mean EBL was 558 mL, mean operative time was 211 min, and mean adenoma weight was 301 g (range 66–640 g). The mean hospital stay was 1 day, and one patient had a complication (bladder neck contracture at 4 months postoperatively) [16]. Limitations of robot-assisted retropubic prostatectomy are concerns for transperitoneal access and longer operative times. For patients with significantly enlarged prostates (>200 g), however, an extraperitoneal approach would prove to be challenging from a technical standpoint due to limited operative space. Not surprisingly, the patient in our series with the longest operative time and highest EBL had the largest adenoma weight (640 g) [16].

Sotelo *et al*. published a series of seven patients who underwent robot-assisted simple prostatectomy via a transperitoneal approach [17]. Their technique involved making a horizontal cystotomy incision proximal to the junction of the bladder and prostate, and performing the dissection of the prostate adenoma intravesically. In their series, the mean operative time was 195 min, mean EBL was 382 mL, mean hospital stay was 1.3 days, and mean specimen weight was 50 g (range 40–64.5 g). Four of their patients experienced postoperative urinary retention [17].

Single port prostatectomy

In 2008, Desai *et al*. first reported on three patients with BPH who underwent single-port transvesical enucleation of the prostate [18]. They later reported on 34 patients who underwent single-site transvesical enucleation of the prostate [21]. One procedure was done with robotic assistance. Nineteen cases (55%) were performed with finger assistance through the TriPort ring. They reported a mean operative time of 116 min (range 45–360 min), mean EBL of 460 mL (range 50–2500 mL), and mean hospital stay of 3 days (range 1–10 days). Four patients were converted to open, and eight patients experienced either an intraoperative or postoperative complication [21].

Comparative studies

There are several comparative studies between laparoscopic and open simple prostatectomy. Porpiglia *et al*. reported a prospective, nonrandomized study comparing open and laparoscopic extraperitoneal approaches for simple prostatectomy using the Millin's technique in both groups (n = 20 in each group) [23]. They reported no difference in any preoperative parameter [age, prostate volume, prostate-specific antigen (PSA), IPSS score]. Patients who underwent laparoscopic prostatectomy had lower blood loss (412 mL vs 688 mL, $P = .004$). No difference was found in operative time, weight of adenoma removed, hospital stay, duration of catheterization, or postoperative complications [23]. Baumert *et al*. compared 30 patients who underwent laparoscopic simple prostatectomy with 30 prior patients who had undergone open simple prostatectomy [24]. Laparoscopic procedures were performed via a Millin's or transvesical technique (n = 17 and n = 13, respectively). They reported a longer operative time for the laparoscopic group, but lower blood loss, shorter irrigation time, shorter catheterization time, and shorter hospital stay. When comparing the laparoscopic Millin's versus laparoscopic transvesical approach, no difference was found between any of the perioperative parameters [24]. McCullough *et al*. compared 280 consecutive nonrandomized patients who underwent laparoscopy using the transcapsular finger-assisted or open transvesical prostatectomy (n = 96 and n = 184, respectively). The laparoscopic approach was associated with a longer operative time, shorter catheter duration, and shorter hospital stay. There was no difference in EBL between the cohorts [22].

Complications

Overall complication rates after minimally invasive simple prostatectomy ranged from 0% to 40%, although methods of reporting complications varied considerably [8, 10–12, 15, 22–24]. The majority of complications were considered minor, and no postoperative deaths were reported. In the comparative series, complication rates were similar between the open and laparoscopic approaches. Baumert *et al.* reported no difference in complications between the laparoscopic (n = 8, 27%) and open (n = 9, 30%) groups. Porpliglia *et al.* reported no difference in postoperative complications between the groups [23]. McCollough *et al*. did not report on overall complication rates between the open and laparosopic groups, but did report a higher rate of recatheterization fistula (3.1% vs 0%, $P = .039$) in the laparoscopic group. The open group, however, had a higher rate of urinary infection (9.8% vs 1%, $P = .012$) and urosepsis (4.9% vs 0%, $P = .030$) compared to the laparoscopic group [22].

In the single-port series from Desai *et al*., eight patients experienced a complication (23%) [21]. Three complications were intraoperative: enterotomy, bleeding requiring transurethral fulguration and transfusion, and bleeding in a Jehovah's Witness resulting in death. Postoperative complications included bleeding requiring transfusion (four patients) and urinary tract infection with epididymitis that responded to antibiotics and Foley catheter drainage [21]. Reported complication rates after robot-assisted simple prostatectomy were 14–33%. Specific complications were postoperative bladder neck contracture in one patient and epigastric artery injury necessitating blood transfusion in one patient [16, 17].

Conclusions

Laparoscopic, robot-assisted, and single-port simple prostatectomy are technically feasible and safe, and achieve comparable results to open simple prostatectomy. As centers of excellence gain further experience with these approaches, their roles in the management of symptomatic BPH will likely expand.

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CHAPTER 94

Laparoscopic and Robotic Surgery of the Seminal Vesicles

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Anatomy and physiology

Seminal vesicles are elongated saccular glands that develop from outgrowths of the mesonephric duct [1]. Located superior to the prostate and juxtaposed by bladder and rectum, the seminal vesicles are invested by Denonvilliers' fascia dorsally and the seminal vesicle fascia ventrally [2]. The seminal vesicles join the ampulla of the vas deferens to form the ejaculatory duct, which courses through the central zone of the prostate to terminate at the verumontanum [3]. Three distinct histologic layers are described: an inner layer of luminal epithelial cells, a middle layer of smooth muscle, and an outer layer of fibrous connective tissue, any of which may give rise to neoplasm [4]. The vesiculodeferential artery is the dominant blood supply to the seminal vesicle with lymphatic drainage primarily to the internal iliac nodes. Along with contributing a majority of the ejaculate volume, the seminal vesicles play a role in male fertility, secreting factors necessary for sperm motility, including fructose, prostaglandins, and coagulations factors [5].

Pathologic conditions

Pathologic lesions of the seminal vesicles are relatively infrequent and include neoplasm, seminal vesicle cysts, and infectious manifestations, including vesiculitis, abscess, and stones. Neoplasms of the seminal vesicles include benign as well as primary and secondary malignancies. Causes of obstruction of the seminal vesicles are variable and their description is beyond the scope of this chapter.

Infection and stones

Infectious manifestations are more common in countries where tuberculosis and schistosomiasis are endemic [6, 7]. Occasionally, removal of the seminal vesicles is necessary in patients with recurrent bacterial seminal vesiculitis not responsive to antibiotics. In immunocompromised patients or those with a recent history of instrumentation, infection may progress to abscess formation, often requiring intervention by surgical or percutaneous drainage. One potential complication of seminal vesicle infection or obstruction is stone formation [8]. Symptoms relating to seminal vesicle stones include chronic pelvic pain, hematospermia, and testicular/postejaculatory pain, and may require vesiculectomy or stone removal once diagnosis is confirmed [9, 10].

Seminal vesicle amyloidosis

Seminal vesicle amyloidosis is a local process distinguished from systemic amyloidosis by its immunohistochemical profile [11]. The most common presenting symptom is hematospermia, although clinical symptoms are rare [12]. Deposits of subepithelial amyloid are reported with variable frequency in older patients and therefore may be concomitant with other malignancies of the pelvis. As with other benign conditions, surgical removal is not necessary in asymptomatic patients.

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Cysts

Seminal vesicle cysts are rare, occurring in less than 0.005% of the male population [13]. Cysts may be either congenital or acquired, are usually asymptomatic, and usually present after puberty [1]. The most frequently reported symptoms include pelvic pain, hematospermia, and urinary retention [14]. Differential diagnosis includes ureterocele, congenital vesicle diverticulum, or cyst of a mullerian remnant, urogenital sinus, ejaculatory duct or prostate [15, 16].

Congenital seminal vesicle cysts may be associated with ipsilateral renal abnormalities, such as renal agenesis/dysplasia [13, 17, 18], polycystic kidney disease [19], as well as ureteral ectopia and ureterocele [20]. This finding suggests a role for upper urinary tract imaging as part of the diagnostic work-up. Acquired cysts are thought to arise from ejaculatory duct obstruction relating to chronic prostatitis, benign prostatic enlargement, prostate surgery or malignancy [21]. Drainage or excision is necessary when associated with infection, compression of adjacent structures, infertility, malignancy degeneration or when cysts become symptomatic [22–25].

Retrovesicle hydatid cysts represent a rare pathologic process of the seminal vesicles resulting from echinococcal disease. This entity is usually accompanied by hydatid cysts in the liver [26]. Therapy involves pretreatment with albendazole followed by aspiration of cyst and injection of cyst cavity with hypertonic saline, hydrogen peroxide, and 10% formalin prior to vesiculectomy or removal of the cyst [27].

Neoplasms

Benign tumors

Papillary adenoma (cystadenoma) are benign mixed epithelial–stromal tumors that appear similar to seminal vesicle cysts on imaging. Criteria for diagnosis include localization of mass to the seminal vesicle without adjacent organ involvement, as well as absence of immunoreactivity to prostatic epithelial markers or carcinoembryonic antigen (CEA) [28, 29]. These lesions may be followed with transrectal ultrasound unless the lesion undergoes malignancy degeneration or becomes symptomatic [28].

Malignant tumors

The challenge with identification and treatment of malignant neoplasms of the seminal vesicle is distinguishing primary from secondary lesions. The frequency of seminal vesicle involvement by locally advanced tumors, such as adenocarcinoma of the prostate, far outweighs frequency of primary neoplasms [30]. Digital rectal exam, transrectal ultrasound imaging, cystoscopy, and sigmoidoscopy should be performed to rule out prostate, bladder, and rectal carcinoma [31]. Unfortunately, physical exam findings are often absent with no detectable abnormality noted on digital rectal examination or cystoscopic evaluation in 30% of patients diagnosed with seminal vesicle carcinoma [32, 33]. Normal serum prostate-specific antigen (PSA), prostatic acid phosphatase (PAP), and CEA suggest absence of secondary invasion by prostate or colonic carcinoma, while elevated CA-125 is strongly suggestive of primary seminal vesicle carcinoma [32, 34, 35].

Most malignant tumors arising from the seminal vesicle are adenocarcinoma. Although range of age at diagnosis is variable, most tumors occur in the sixth decade [31]. Clinical manifestations include hematuria, hematospermia, pelvic pain, dysuria, and urinary retention [31, 36]. Additionally, displacement of the trigone and ureteral obstruction may occur [34, 37]. Histopathologic diagnosis is usually made by transrectal ultrasound-guided needle biopsy, although in cases of bladder or prostate invasion transurethral resection may provide tissue diagnosis. Additionally, immunohistochemistry profile with positive CA-125, positive cytokeratin-7, and negative cytokeratin-20 can aid in differentiating seminal vesicle carcinoma from other pelvic tumors [31, 32, 35, 37]. Additionally, response to treatment may be monitored by following serum CA-125 levels [35].

Although initial reports demonstrated a poor prognosis, recent series have shown disease-free intervals of up to 50 months with organ-confined disease [36]. While there is no clear consensus on the extent of resection required in all patients, it is generally believed that tumor confined to the seminal vesicles may be removed by vesiculectomy if clear margins are accomplished [31]. If ejaculatory duct invasion is suspected, prostatovesiculectomy should be performed [38]. Aggressiveness of extirpation is directly related to suspected degree of local organ involvement.

Few cases of sarcoma of the seminal vesicles are reported, including leiomyoma, leiomyosarcoma, and fibrosarcoma [39]. Additionally, biphasic variants have been noted in the literature, including a cystic epithelial–stromal tumor and cystosarcoma phyllodes of the seminal vesicles [40, 41]. Radical extirpation is usually required due to aggressive behavior.

Examination findings

Signs and symptoms of seminal vesicle pathology are relatively vague and nonspecific. The most frequently reported symptoms include perineal or pelvic pain, painful ejaculation, urinary retention, irritative voiding symptoms, infertility, and hematospermia. Because hematospermia is often self-limiting, work-up is not recommended unless in the presence of gross hematuria, infertility, or complaints relating to voiding or ejaculation.

Physical examination findings are limited. Occasionally masses, which may have either discrete or poorly defined margins, may be appreciated in the rectal examination. Cystoscopic findings within the bladder may reveal ipsilateral elevation of the trigone, distortion of the intertrigonal ridge, or no significant findings. Within the prostatic urethra, endoscopic findings include distortion of the verumontanum, patulous ejaculatory ducts or midline cysts [42]. Urinalysis findings may include microscopic hematuria, while semen analysis may reveal hematospermia, bacteria, or in the case of obstruction, low fructose levels.

Radiographic diagnosis

Transrectal ultrasound

Diagnosis of seminal vesicle disease often requires the assistance of radiographic imaging. Transrectal ultrasound (TRUS) is the most frequently used modality for imaging seminal vesicle pathology and is the initial study of choice. Seminal vesicles should be recognized as paired saccular organs just cephalad to the prostate with an echopenic center and echogenic vesicle walls [43]. Pathologic conditions demonstrated on TRUS include congenital cysts, which may be associated with renal aplasia or ureteral ectopia. These lesions appear as well-marginated anechoic masses contiguous with the seminal vesicle and in some instances, displacing adjacent structures [44]. Primary malignancies may be recognized as unilateral lesions, while secondary tumors are usually contiguous with the adjacent organ of primary tumor and frequently involve both seminal vesicles. No other imaging characteristics delineate benign from malignant tumors [45]. Biopsy or aspiration of lesions at the time of TRUS may be both therapeutic and diagnostic.

Computed tomography

Computed tomography (CT) allows imaging of the seminal vesicles, adjacent pelvic organs, and when necessary, the entire retroperitoneum. Seminal vesicles appear as paired organs caudal to the bladder with attenuation similar to that of soft tissue. Cysts are readily identified as well-defined, fluid-filled structures with Hounsfield unit characteristics of fluid (Figure 94.1), with the exception of hemorrhagic or infected cysts, which may show increased attenuation. Calcifications may be recognized in chronic infectious or inflammatory conditions, while long-term diabetes may demonstrate diffuse seminal vesicle calcifications [46]. Finally, CT cannot reliably distinguish benign from malignant or primary from secondary lesions. Unilateral lesions with intact tissue planes may suggest primary neoplasm. All solid or heterogenous appearing lesions require a histologic diagnosis.

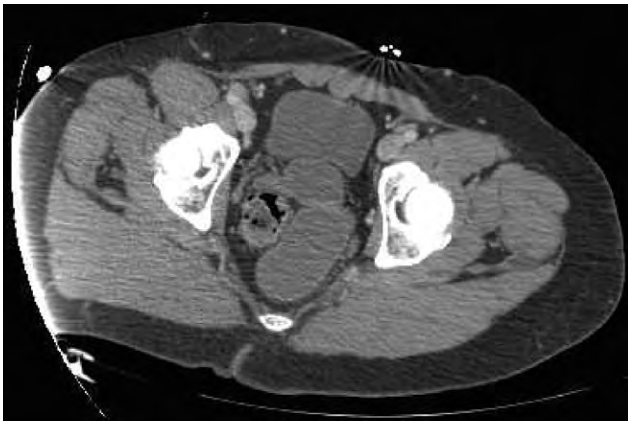

Figure 94.1 CT scan of patient with seminal vesicle cyst.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) provides anatomic information similar to that of CT, with the advantage of more precise delineation of tissue planes, which may improve preoperative staging of seminal vesicle tumors. Seminal vesicles appear to have low signal intensity on T1-weighted imaging and high intensity on T2-weighted imaging. Cysts have characteristic high intensity on T2-weighted imaging, which in hemorrhagic cysts may be accompanied by high T1-weighted imaging characteristics [44]. Diffuse wall thickening may be seen with both seminal vesiculitis and amyloidosis, and the latter demonstrates low T2-weighted and high T1-weighted imaging [47–49].

Although MRI cannot reliably distinguish between benign and malignant tumors, secondary neoplasms may be suggested by obliteration of adjacent tissue planes in the context of suspected malignancy. The most common secondary malignancy of the seminal vesicle is adenocarcinoma of the prostate. The sensitivity and specificity of MRI to detect seminal vesicle invasion by prostate cancer is 50–71% and 66–95%, respectively [50].

Surgery of the seminal vesicle

Minimally invasive surgical approaches

Open surgical approaches for treatment of seminal vesicle disease are variable, including retrovesicle, transvesicle, transperineal, and transcoccygeal. Significant complications have been associated with open vesiculectomy, including rectal wall laceration, ureteral injury, and pelvic urinoma [45]. With increased experience with endoscopic, laparoscopic, and robotic techniques, most benign conditions and primary tumors of the seminal vesicles may be approached by minimally invasive techniques. The following section will focus on these treatment options.

Indications

Indications for operative intervention of seminal vesicle disease include presence of symptomatic seminal vesicle cyst, abscess, stone or chronic infection. Surgical extirpation of solid primary seminal vesicle masses is often indicated since imaging fails to differentiate benign from malignant neoplasms. Additionally, patients with seminal vesicle disease associated with an ectopic ureter and ipsilateral renal dysplasia may require extirpation, depending on the clinical scenario.

Prior to surgical intervention, patients may wish to cryopreserve sperm if both future fertility is desired and concern exists for intraoperative compromise of both ductal systems.

Endoscopic approaches

Endoscopic techniques for treatment of seminal vesicle conditions include treatment of ejaculatory duct obstruction, as well as seminal vesicle cysts or abscess in close juxtaposition to the prostatic urethra or bladder. Additionally, recent reports describe diagnostic and therapeutic endoscopic management of seminal vesicle stones.

Transurethral resection of the ejaculatory ducts (TURED) is offered to azoospermic men with suspected ejaculatory duct obstruction. Typically, the proximal verumontanum is resected in the midline using cutting current, after which fluid should be expressed from seminal vesicles to confirm patency. Resection should remain distal to the bladder neck and proximal to the external sphincter. In men with infertility secondary to congenital ejaculatory duct obstruction, improvements in semen parameters may be significant [47]. Patients must be aware of the potential risk of recurrent epididymitis secondary to reflux of urine as a result of the procedure.

Seminal vesicle cysts may be located in close proximity to either the trigone or prostatic urethra. Transurethral or transvesicle incision of the cyst using a Collins knife, electrocautery or a holmium laser has been demonstrated to provide adequate drainage and is generally considered effective and safe [48, 49]. Similarly, abscesses of the seminal vesicle have been drained transurethrally in a similar fashion with success [50].

Seminal vesicle stones may be accessed transurethrally by advancing a 6.9 F flexible or a 7 F semi-rigid ureteroscope into the utricular orifice and directing the scope into the seminal vesicle with or without guidewire assistance. Stones may be fragmented and extracted using conventional endoscopic manipulation. Interestingly, patients in two case reports undergoing treatment for seminal vesicle stones had both undergone prior TURED [10, 51].

While these methods report varied degrees of success, endoscopic treatments of seminal vesicle disorders appear largely to be temporary measures with a high incidence of pathology recurrence and infection [52–55]. Additionally, many of the open approaches for treatment of seminal vesicle disorders have been replaced with laparoscopic and robotic techniques. Laparoscopic magnification combined with the versatility of a 30° lens allow for superior visualization of the retrovesicle space compared to open approaches [56]. Finally, improved patient outcomes relating to decreased postoperative pain, lower patient morbidity, shorter hospital stay and earlier convalescence are reported with laparoscopic and robotic approaches [57, 58]. For this reason, treatment of most seminal vesicle pathology favors laparoscopic and robotic modalities when treatment is necessary.

Laparoscopic approach

The laparoscopic approach to the seminal vesicles was first described in 1993 by Kavoussi *et al.* [59]. Seminal vesicles may be accessed by transperitoneal or retroperitoneoscopic routes. Laparoscopic procedures vary from cyst decortication to vesiculectomy or prostatovesiculectomy.

The transperitoneal approach is similar for patients undergoing cyst decortication, seminal vesiculectomy or prostatovesiculectomy. Appropriate perioperative antibiotics and deep vein thrombosis prophylaxis are administered. After induction of anesthesia, arms are padded and tucked, and the patient is placed in steep Trendelenburg to facilitate bowel mobilization. Pneumoperitoneum is established via supraumbilical placement of a Veress needle. A 12-mm port is placed just above the umbilicus and the peritoneum is inspected with a 30° laparoscope. Two 5-mm ports are placed 9 cm inferolateral to the umbilical port toward the ipsilaral anterior superior iliac spine. A 12-mm port is placed 6 cm lateral to the right 5-mm port.

Adhesions are lysed and the sigmoid colon is mobilized out of the pelvis; we prefer a paddle retractor for bowel retraction. The peritoneum is incised in midline 3 cm above the junction of the bladder and rectum, and opened transversely [9]. Seminal vesicles are usually easily identified in this location with a mixture of blunt and sharp dissection. In the event the seminal vesicles are not readily apparent, the ipsilateral vas should be identified at the external inguinal ring and traced medially. An incision can be made in the peritoneum medial to the right medial umbilical ligament over the vas. The right vas is traced towards the midline and the peritoneum is subsequently incised over the left vas toward the left medial umbilical ligament [56]. Once identified, the circumferential dissection of the seminal vesicle proceeds medial to lateral, and dissection is kept strictly adherent to the gland in order to avoid injury to the neurovascular bundle or adjacent structures, particularly the ureter located near the tip of the seminal vesicle [9, 58]. Denonvilliers' fascia is demonstrated posteriorly and separates the seminal vesicles from the rectum. As such, care should be taken to avoid excessive cautery in this area. The dominant artery is usually noted at the tip of the seminal vesicle. Clipping this vessel and dividing without cautery further marginalizes potential damage to adjacent nerves. The vas is clipped and divided and medially the ejaculatory duct is transected at the entrance to the prostate. The seminal vesicle is subsequently placed in an EndoCatch bag and extracted through one of the 12-mm ports. The surgeon may opt to plicate the prostate tissue adjacent to the divided ejaculatory duct with 3-0 Vicryl [20]. Most advocate reapproximating the peritoneum with absorbable suture and closure of the 12-mm ports with a 0 Vicryl suture.

In the case of symptomatic cysts in patients who wish to preserve fertility and sexual potency, decortication of the cyst may be performed if no concern for malignancy exists. In this instance the peritoneum overlying the cyst is incised transversely and the cyst is exposed [60]. Dissection of the most medial and lateral aspects of the seminal vesicle is avoided to prevent potential injury to the ejaculatory ducts and neurovascular bundle, respectively. The cyst is aspirated if necessary and decortication is performed by freeing the cyst from the posterior wall of the bladder, the anterior wall of the rectum, and the seminal vesicles laterally. Finally, the cyst is divided from its base with electrocautery, leaving a narrow strip of cyst wall on the vas [61].

Some authors advocate filling of the seminal vesicle cyst with contrast prior to removal via cannulation of the ipsilateral ejaculatory duct with a 3F ureteral catheter to confirm the diagnosis. Additionally, filling of the cyst with dilute methylene blue to facilitate intraoperative demarcation of cyst margins has been described via cannulation of the ejaculatory duct with a small catheter. Alternatively, direct injection of the ipsilateral vas with methylene blue using a 25G needle after mobilizing the vas through a small scrotal incision may be performed to facilitate cyst localization [60, 62].

Review of 12 case reports of laparoscopic seminal vesicle excision demonstrates total operative time ranging between 90 min and 364 min, with mean operative time of 183 min. Hospitalization varied from 1 to 5 days, with a 2-day average length of stay. No significant complications were documented [55–58, 60].

Retroperitoneal approach

Retroperitoneoscopic extirpation of the seminal vesicles is done in patients who require removal of the prostate. In short, a small incision is made near the umbilicus through which a balloon trocar is inserted. The balloon is inflated under direct vision to create the retroperitoneal space, after which the remaining trocars are placed and the retroperitoneal space is insufflated [45]. The dissection of the seminal vesicles follows transection of the bladder neck and incision of the ventral lamella of the seminal vesicle fascia.

Robotic approach

The da Vinci Surgical System™ (Intuitive Surgical Inc, Sunnyvale, CA, USA) provides a platform that facilitates performance of complex laparoscopic procedures by providing the surgeon with three-dimensional visualization, tremor reduction, ease of suturing, and increased degrees of freedom over traditional laparoscopy [62]. While the approach and dissection of the target tissue are essentially the same as they are for the laparoscopic approach described above, the decision to utilize the robot is based on surgeon preference. Operative times are comparable to those of seminal vesiculectomy performed laparoscopically [20, 63].

Trocar spacing is similar to that described in the previous section (Figure 94.2). We recommend use of a 0° lens and placement of the camera port no closer than 15 cm and no further than 19 cm from the pubic symphysis. In this instance, the 5-mm ports are replaced by 8-mm trocars. We place a third 8-mm port 6 cm lateral to the left 8-mm port and utilize the fourth robot arm for retraction of the bowel. We utilize monopolar scissors and bipolar Maryland forceps for dissection.

The cul-de sac is inspected and peritoneum overlying the seminal vesicles is incised (Figures 94.3 and 94.4). In the patient shown in these figures, future fertility was not a concern and we therefore used the vas for medial retraction (Figure 94.5). The circumferential dissection remains strictly adherent to the seminal vesicle (Figure 94.6). Control of vessels and removal proceed similarly to in the laparoscopic approach previously described.

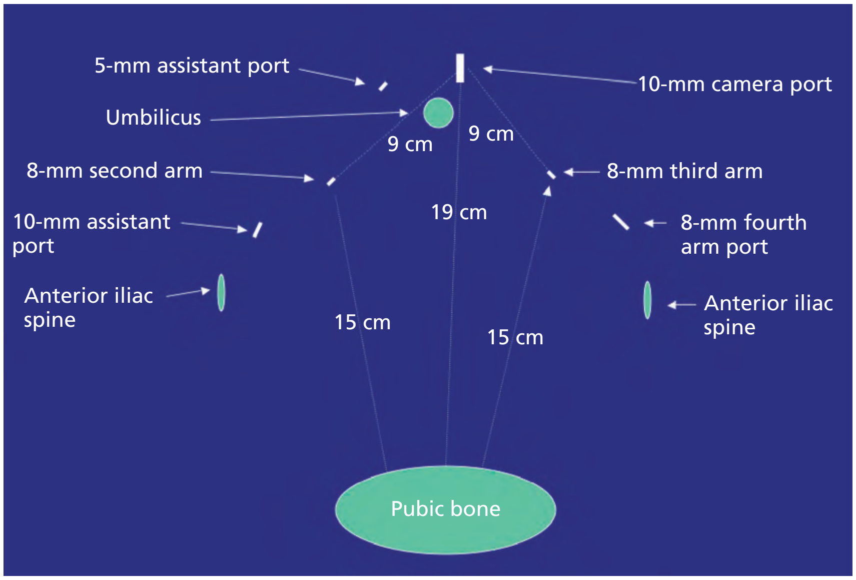
5-mm assistant port
10-mm camera port
Umbilicus
9 cm
9 cm
8-mm second arm
8-mm third arm
19 cm
10-mm assistant port
8-mm fourth arm port
Anterior iliac spine
Anterior iliac spine
15 cm
15 cm
Pubic bone

Figure 94.2 Robotic port configuration for surgery of the seminal vesicles.

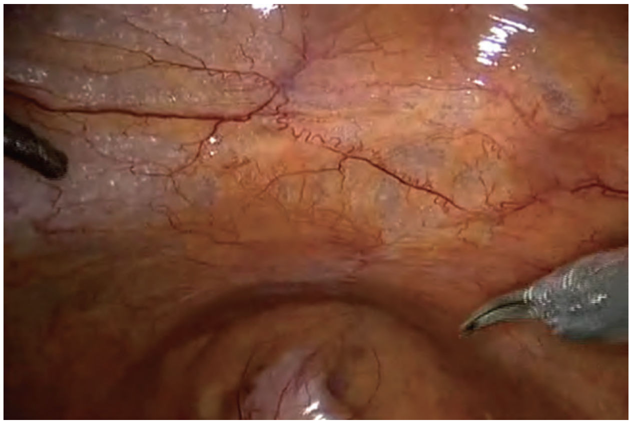

Figure 94.3 Robotic view of cul-de-sac.

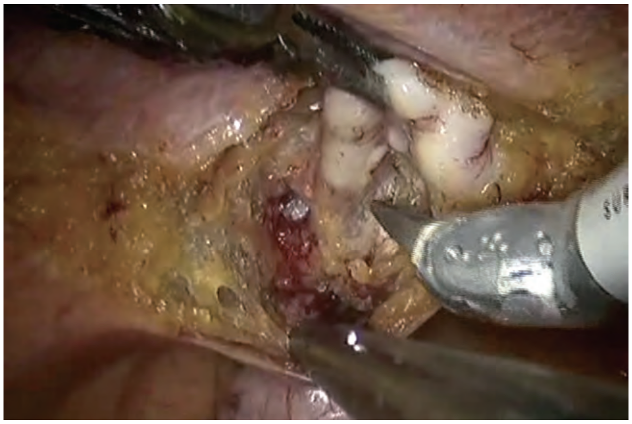

Figure 94.5 Dissection of vas for medial retraction.

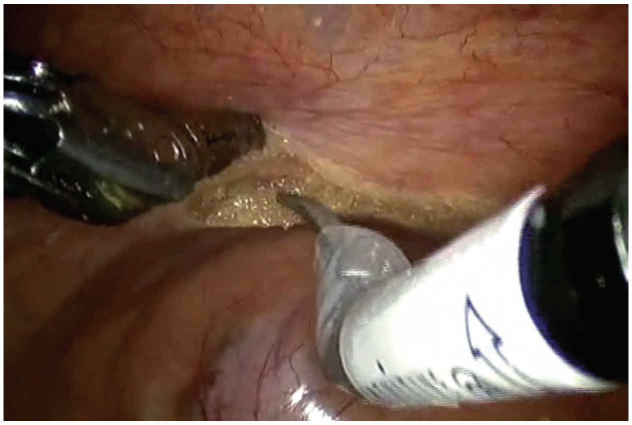

Figure 94.4 Incision of peritoneum overlying seminal vesicles.

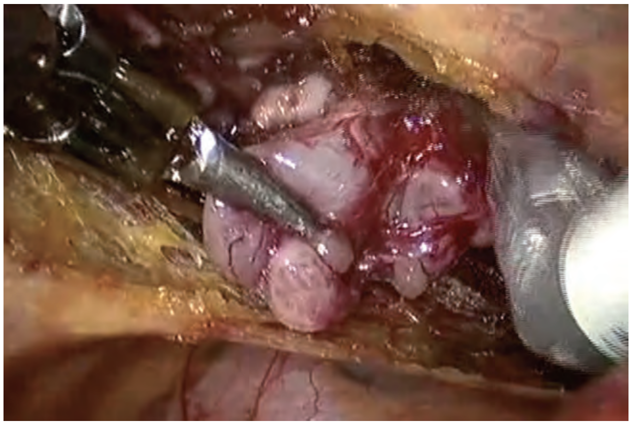

Figure 94.6 Dissection of seminal vesicle.

Conclusions

A variety of seminal vesicle pathologies exist. Diagnosis often requires a combination of radiographic and histopathologic findings. Most conditions requiring surgical treatment may be approached using endoscopic, laparoscopic or robotic techniques.

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CHAPTER 95

Laparoscopic Abdominal Wall Hernias: Incisional, Parastomal, and Inguinal Hernia Repairs

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Abdominal wall incisional and parastomal hernias

Abdominal wall hernia following major genitourinary or abdominal surgery is a significant surgical problem. It has been reported that up to 26% of patients who undergo major abdominal surgery can develop an abdominal wall hernia [1–3]. Factors that may predispose a patient to the formation of such hernias include multiple abdominal surgeries, infection, obesity, poor nutritional status, and chronic medical problems, especially pulmonary, all of which interfere with the normal healing process.

Traditionally, the repair of abdominal wall hernias has been approached via an open technique. A wide variety of techniques have been developed, such as those described by Stoppa and Wantz [4, 5]. However, the recurrence rate after open suture incisional hernia repair has been reported to be as high as 54% [6, 7]. While the introduction of prosthetic material in incisional hernia repair has decreased the recurrence rates, the risk of wound infections and local wound complications may be increased [8–13]. Due to the high recurrence rates, and subsequent reattempts at repair followed by increasingly higher recurrence rates, an alternative to open surgery is attractive.

With the advent of laparoscopic surgery, a new form of hernia repair is now available to surgeons. The goal of the laparoscopic approach to abdominal hernia repair should be to decrease recurrence rates and wound complications, while offering the patient the advantages of a minimally invasive procedure. The first laparoscopic incisional hernia repair was reported in 1993 [14]. Since that time, studies comparing open and laparoscopic abdominal wall hernia repair have suggested that patients who undergo laparoscopic hernia repair experience the predicted advantages of less pain and shorter hospitalization, while the recurrence rate and complication rates are lower [15, 16].

Parastomal hernia following formation of an ileostomy or colostomy is not uncommon. This condition is associated with 1.8–28.3% of end ileostomies and 4–30.8% of end colostomies [17]. These rates are somewhat lower following loop ileostomies and colostomies. The site of stoma formation (through or lateral to the rectus abdominis), trephine size, fascial fixation, and closure of lateral space are not proven to affect the incidence of hernia. If repair is required, a prosthetic mesh technique should be considered, especially if the hernia is recurrent [17, 18] (Figure 95.1).

Indications

The laparoscopic approach may be considered for repair of any form of incisional abdominal, flank or parastomal hernia that may occur following genitourinary surgery. However, general recommendations are that if the hernia size is greater than 15 cm in transverse dimension, a laparoscopic approach may not be optimal and may be severely limited by the working space requirements. In this case an open approach such as myofascial rectus abdominis flaps (the separation of parts

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technique) may be preferable for incisional hernias [19]. For very large parastomal hernias, an open approach with mesh and/or relocation of the stoma may be preferred. Mesh should be generally avoided in the presence of suspected infection or a history of radiation. Comorbidities such as obesity, peripheral vascular or heart disease may favor the laparoscopic approach as the speed of the procedure, lack of significant third spacing of fluids, avoidance of significant ileus, and decreased pain all help the more ill patient with a symptomatic hernia [19].

Patient preparation

All patients undergo preoperative imaging by computed tomography (CT) scan, with a concurrent loopogram performed in the case of parastomal hernias, to determine the contents of the hernia and define the extent of the fascial defect (Figure 95.2). All patients receive oral antibiotics and a full mechanical bowel preparation with Golytely®, and are typed and screened for blood products. Patients are routinely given one dose of broad-spectrum antibiotics on call to the operating room.

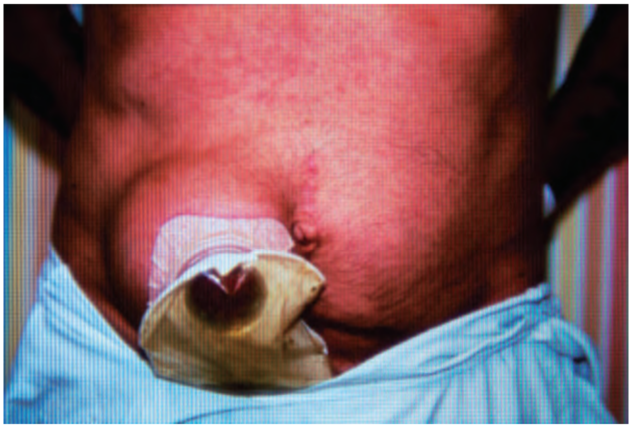

Figure 95.1 Parastomal hernia following ileal conduit formation.

Surgical technique

Prior to performing the laparoscopic repair, an orogastric tube is placed for gastric decompression and a 16F Foley catheter is placed in the bladder or stoma of the urinary diversion in the case of a parastomal hernia repair.

Under general anesthesia, the Hasson cannula technique is used to obtain an initial pneumoperitoneum. The location of the initial entry port is at a site farthest away from the hernia defect and surgical incision, so as to minimize the risk of entry into an area of adhesions or bowel. In other words, if the hernia were in the right mid/lower abdomen, the Hasson cannula entry would be at the left upper quadrant. The working port size, number, and placement are dependent on the location, type, and size of the hernia. Generally three to four ports (5–11 mm) are required. The basic objective is to space out the ports in a triangular fan-shape configuration with the apex of the triangle directed to the hernia. Adhesiolysis is achieved with both blunt and sharp dissection. The hernia contents are emptied and the fascial edges are freed circumferentially of overlying tissue beyond 3 cm (Figure 95.3). The mesentery supplying the ileal or colonic conduit is carefully identified and preserved, with separation from surrounding herniated bowel in the case of parastomal hernia repairs (Figure 95.4).

The circumferential dimensions of the hernia defect are measured by percutaneously placing an 18G spinal needle under laparoscopic guidance through the edge of the fascial defect. Once the size of the defect is determined, a piece of polytetrafluoroethylene Gore-Tex®

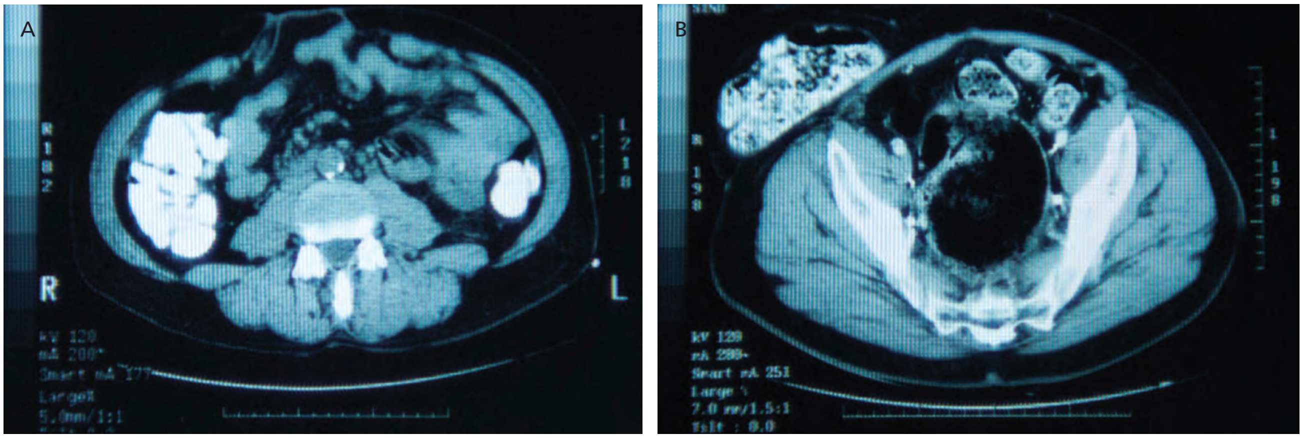

Figure 95.2 (A, B) Incisional hernia following radical cystectomy.

DualMesh product (W.L. Gore & Associates, Flagstaff, AZ, USA) is cut 2–4 cm larger. Four quadrant stitches of 2-0 Gore-Tex® are placed on the mesh, which is then rolled up and inserted into the abdominal cavity through a 10/11-mm port site. The DualMesh has a smooth side with a pore size of less than 3 μm, which diminishes adhesion formation to bowel, and a rough side with a pore size of 22 μm, which allows more ingrowth of fibroblast and collagen. The smooth side is oriented towards the bowel contents and the rough side towards the abdominal wall. The mesh is positioned and the quadrant stitches brought out percutaneously using the Carter Tomlinson® device (Inlet Medical, Eden Prairie, MN, USA). The helicoidal staples (ProTack®; Autosuture Inc, Norwalk, CT, USA) secure the Gore-Tex® mesh to the fascia edge beyond the defect. Tacks are placed every 1.5 cm around the outer edge of the defect. In the case of a parastomal hernia, a radial incision is made in the Gore-Tex® mesh such that the wings can be wrapped behind the stomal loop of bowel and secured in place (Figure 95.5). We have found it easiest to fashion the radial incision within the abdominal cavity after the mesh has been partially secured, rather than trying to anticipate the location *ex vivo*. Final hemostasis is obtained and the port sites are closed in the usual fashion.

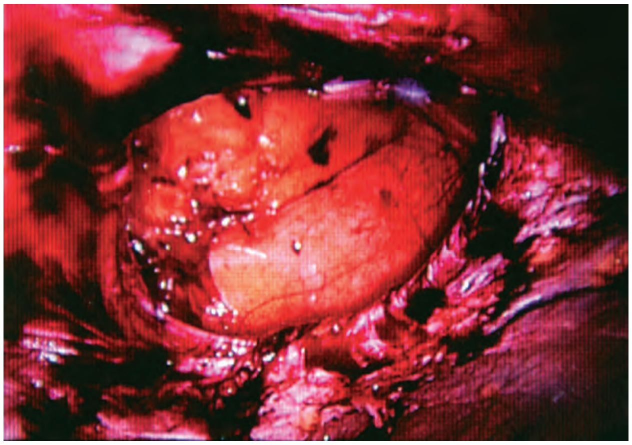

Figure 95.3 Intraperitoneal borders of incisional hernia defined.

Postoperative care

An abdominal wall compressive dressing is placed at the termination of the procedure so as to reduce the development of postoperative seromas, and the patient is encouraged to wear an abdominal wall binder as much as possible over the ensuing 6 weeks. Discharge from hospital is variable but usually occurs within 1–3 days, depending on the size of the hernia repair, postoperative pain, and resolution of any adynamic ileus. Strenuous or lifting activities are discouraged for 6 weeks.

Results

Laparoscopic incisional hernia repair has gained increasing popularity as a result of the low recurrence and complication rate of the procedure, as well as improved patient postoperative course. Table 95.1 lists some recent studies of laparoscopic incisional hernia repair [20–26]. Most surgeons are using expanded polytetrafluoroethylene (PTFE) in their repairs. The recurrence rates appears to be 2–4%, but has been reported as high as 9% depending on the study and the surgeons' experience. Mean follow-up is reasonable at 22.5 months. The most

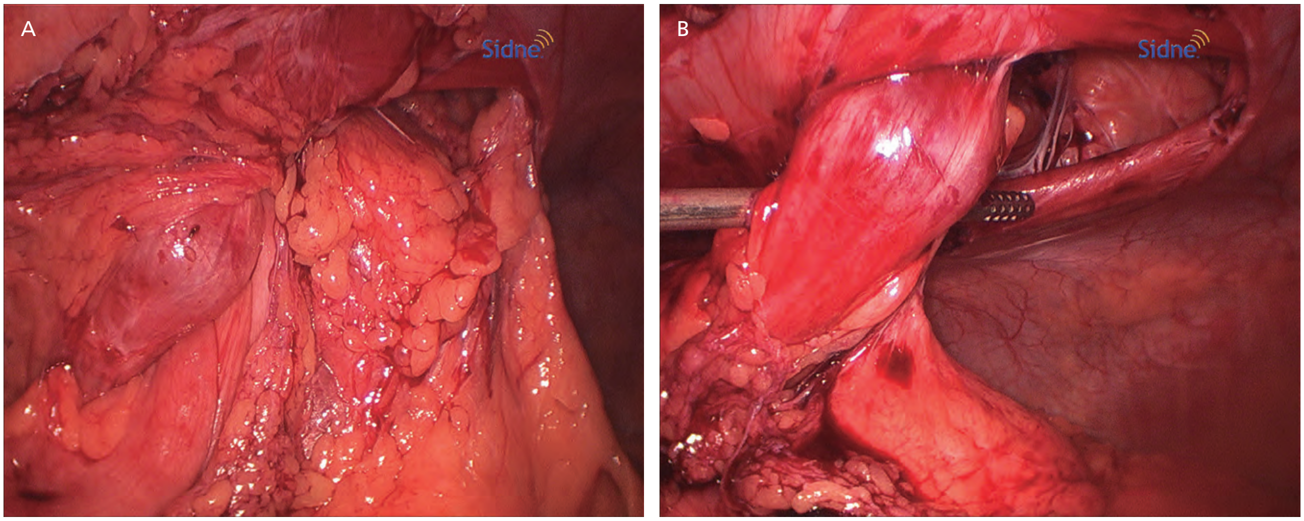

Figure 95.4 (A, B) Borders of parastomal hernia defined with preservation of mesentery of ileal conduit.

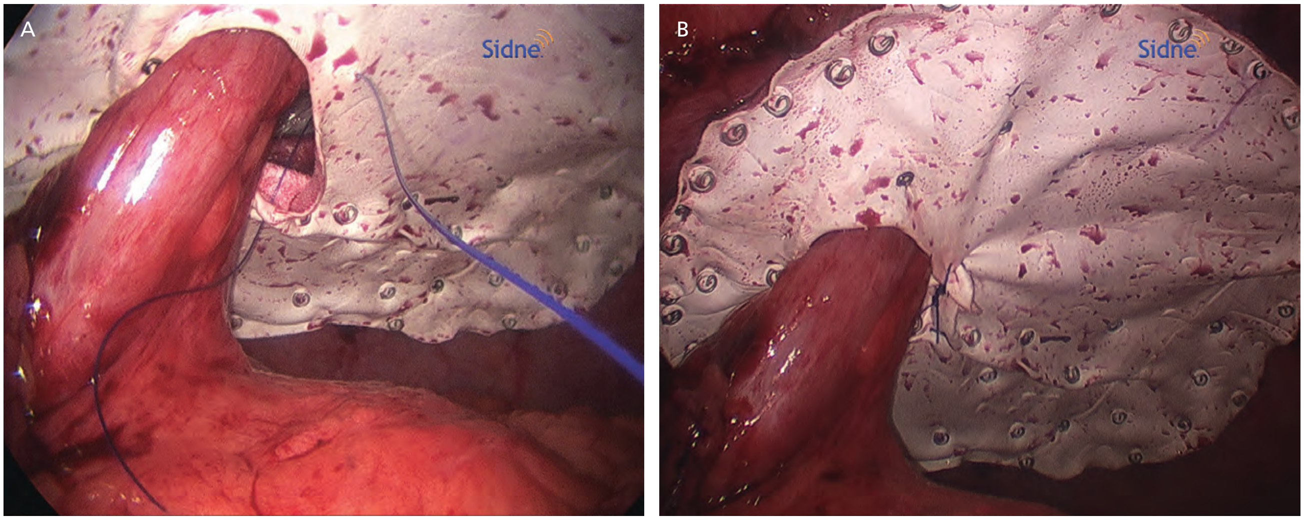

Figure 95.5 (A) Gore-Tex® DualMesh wrapped around ileal conduit and (B) tacked to close off parastomal hernia.

Table 95.1 Studies of laparoscopic incisional hernia repair.

Study	Type of mesh	Number. of patients	Recurrences (%)	Follow-up (months)
Franklin *et al.* [20]	Polypropylene	176	1	30
Toy *et al.* [21]	PTFE	144	4	7
Carbajo *et al.* [22]	PTFE	100	2	30
Chowbey *et al.* [23]	Polypropylene	202	1	35
Heniford and Ramshaw [24]	PTFE	100	3	22
Heniford *et al.* [25]	PTFE	407	3	23
LeBlanc *et al.* [26]	PTFE	96	9	51

Table 95.2 Studies comparing laparoscopic mesh and open mesh incisional hernia repair.

Study	Type of repair	Number of patients	Recurrences (%)	Follow-up (months)
Carbajo *et al.* [28]	Open	30	7	27
	Laparoscopic	30	0	27
Ramshaw *et al.* [15]	Open	174	21	21
	Laparoscopic	79	3	21
Chari *et al.* [29]	Open	14	0	6–27
	Laparoscopic	14	0	6–27
Zanghi *et al.* [30]	Open	15	0	40
	Laparoscopic	11	0	18

frequent complications with laparoscopic incisional hernia repair are unresolving seromas (1–36%), wound infections (0–6%), ileus (1–10%), bowel injury (0–6%), and prolonged pain (0–2%) [27].

Finally, four studies comparing laparoscopic mesh and open mesh incisional hernia repair suggest that the recurrence, complication, and hospitalization rates are lower with the laparoscopic approach (Table 95.2) [15, 28–30]. However, only one of these clinical studies is randomized [28].

Sizeable studies of laparoscopic parastomal hernias are currently unavailable in the literature. Most studies consist of case reports or small series. Our own study consists of four patients who have all done well with the use of DualMesh at greater than 12 months follow-up [31]. There have been no complications or recurrences noted in this small series.

The most dangerous and time-consuming part of the procedure is the lysis of bowel and omental adhesions from the abdominal wall, and the reduction of the hernia contents. Adhesiolysis should be performed with judicious use of electrocautery or the Harmonic shears (Ethicon Endo-surgery, Cincinnati, OH, USA), especially in close proximity to the bowel. Careful inspection of the abdominal cavity after placement of the mesh for bleeding or bowel injury is mandatory. In the event of an iatrogenic enterotomy, the original standard of care is repair of the injury by laparoscopic means or laparotomy and removal of the mesh. Placement of the mesh (i.e. foreign body) in this situation is discouraged. Some authors, however, have reported placing the mesh laparoscopically in the face of only an isolated bowel injury in patients who have undergone a very thorough bowel preparation, who have no other risk factors such as steroids, and in whom the injury is recognized immediately and spillage has not occurred [32].

In the presence of potentially contaminated abdominal wall defects, the use of Surgisis (Cook Surgical, Bloomington, IN, USA), a four-ply bioactive, prosthetic mesh derived from porcine small-intestine submucosa, might be considered [33].

Of the currently available prosthetic materials, Gore-Tex® mesh has been shown to have the lowest foreign body reaction, rate of adhesion formation, and infection rate [34, 35]. An alternative popular material is the Composix® E/X mesh (Davol Inc, Cranston, RI, USA).

Laparoscopic inguinal herniorrhaphy

Schlegel and Walsh reported that inguinal hernias may be present in 5–12% of men with clinical prostate cancer [36]. In the urologic community, these authors popularized the transabdominal preperitoneal repair of inguinal and femoral hernias at the time of pelvic surgery. Subsequent reports confirmed the usefulness of preperitoneal herniorrhaphy concurrent with urologic procedures in both children and adults [37–39]. With the explosion of interest in laparoscopy- and robot-assisted radical prostatectomy, and given that one in 10 men undergoing laparoscopic pelvic lymphadenectomy or prostatectomy might have an inguinal hernia, proficiency in laparoscopic herniorrhaphy would obviate the need for reoperation under a second anesthetic, minimize morbidity for the patient, and reduce overall costs to the healthcare system.

As advances in technology and refinements in techniques improve the outcomes of laparoscopic inguinal hernia repair, the procedure will be performed more often. In the future, urologists will encounter more and more patients who have undergone such repairs. Indeed, there have been reports of laparoscopic inguinal herniorrhaphy complicating subsequent radical retropubic prostatectomy, even forcing the procedure to be aborted in some cases [40–42]. It would therefore benefit any urologist to be familiar with laparoscopic inguinal herniorrhaphy.

Indications

Laparoscopic inguinal herniorrhaphy may be performed for direct or indirect defects, including primary, recurrent, and bilateral inguinal hernias, as well as for femoral hernias.

Patient preparation

Preoperative studies

For the patient for whom laparoscopic urologic surgery is planned, careful examination of the inguinal region with the patient in the upright position during a Valsalva maneuver may reveal the presence of an otherwise asymptomatic hernia. As for all laparoscopic surgery, routine blood work and radiologic imaging is obtained based on the patient's age and medical history. Even if the urinalysis is not suggestive of infection, a urine culture is recommended to exclude this avoidable source of prosthetic infection, especially if the hernia repair is to be done concurrently with a urologic procedure that allows urine into the surgical field (i.e. radical prostatectomy).

Medications

All anticoagulants, nonsteroidal anti-inflammatory agents, and Aspirin-containing products are discontinued for 7 days preoperatively. Bowel preparation is administered at the discretion of the surgeon. Intravenous broad-spectrum antibiotics, while not strictly required in a "clean" surgical case, are prudent when prosthetic material is to be implanted.

Informed consent

Assuming that the patient is to undergo laparoscopic herniorrhaphy concurrently with another laparoscopic procedure, a discussion of the risks and benefits of laparoscopy in general should have already taken place. Potential complications specific to laparoscopic inguinal hernia repair are discussed later. The patient is advised that the primary urologic procedure takes precedence; if laparoscopic herniorrhaphy at the conclusion of the procedure does not appear likely to proceed uneventfully due to a difficult previous dissection in the pelvis, bleeding, anesthetic considerations, or other reasons, then it may be postponed. The patient is preoperatively given the option of an open hernia repair under the same anesthetic if the urologist decides against the laparoscopic approach intraoperatively.

Positioning of equipment and personnel

The main video monitor, insufflator, video unit, light source, and electrosurgical generator are located on a movable cart placed at the foot of the operating table, thereby allowing the surgeon an unobstructed view of the monitor and instrument indicators.

Patient positioning

The patient is placed supine in a moderate head-down tilt with the ipsilateral side rotated upward. Arms should be tucked by the side so that they do not impede the movement of the primary surgeon. A Foley catheter should be placed to drain the bladder and an orogastric tube placed to decompress the stomach.

Inguinal–pelvic anatomy

The key to successful and safe laparoscopic herniorrhaphy is a thorough understanding of the inguinal–pelvic anatomy. Urologists familiar with laparoscopic pelvic surgery are experienced in identifying these structures from a laparoscopic perspective. A brief review will nonetheless facilitate subsequent explanation of the procedural steps.

The first landmarks evident from the intraperitoneal perspective are the three umbilical ligaments, all formed by peritoneal folds overlying preperitoneal tubular structures. The median umbilical ligament, over the obliterated urachus, is directly in the midline extending from the dome of the bladder to the umbilicus. The medial umbilical ligaments, representing the obliterated umbilical arteries, are usually the most prominent structures, but may be obscured by preperitoneal fat in some patients. They are oriented in an inverted V shape, running from the deep pelvic space medial to the external iliac vessels and lateral to the bladder up along the anterior abdominal wall toward the midline. All dissection for unilateral laparoscopic herniorrhaphy is performed lateral to the medial umbilical ligaments. Between the medial and inferior epigastric vessels lies the medial fossa, where direct inguinal hernias occur. The lateral fossa is just lateral to the inferior epigastric vessels, wherein lies the internal inguinal ring, the site of indirect inguinal hernias.

Within the preperitoneal space lie the structures responsible for creating the umbilical ligaments: the urachus, umbilical arteries, and inferior epigastric vessels. Other pelvic structures in this space are the vas deferens, external iliac vessels, the deep circumflex iliac vessels, and pubic or accessory branches of the inferior epigastric vessels. The courses of these arteries and veins are best understood in terms of their relationship to the transversalis fascia analogs (the iliopubic tract, Cooper's ligament, and iliopectineal arch), which are the thickenings and condensations of the transversalis fascia that define the layer external to the preperitoneal space. Whereas the inguinal ligament is the landmark often used by inguinal surgeons, the best landmark for the laparoscopist performing herniorrhaphy is the iliopubic tract. This strong fascia runs from the iliac crest and anterior superior iliac spine inferiorly and medially to curve around the femoral sheath and attach to Cooper's ligament and the pubic tubercle. It forms the medial border of the internal inguinal ring and the lateral border of the femoral ring (Figures 95.6 and 95.7). Cooper's ligament is seen by the laparoscopist as the white ligament coursing back from the pubic ramus under the distal portion of the external iliac vessels to lie at the inferomedial border of the femoral ring. The iliopectineal arch and the underlying aponeurotic arch of the transversus abdominis run lateral to the iliopubic tract, forming the lateral border of the internal inguinal ring, and then insert along with the iliopubic tract on the pubis and Cooper's ligament. The triangular space created by the iliopubic tract and aponeurotic arch inferior (distal) to the inferior epigastric vessels and internal inguinal ring is the weak point in the medial fossa through which direct herniation occurs. An indirect hernia is seen laparoscopically as an orifice lateral and superior to the inferior epigastric vessels (Figure 95.7).

The testicular vessels laterally and the vas deferens medially form the "triangle of doom" for the novice surgeon performing laparoscopic herniorrhaphy (Figure 95.7). This triangle containing the proximal portion of the external iliac vessels is the area where the urologist performs laparoscopic pelvic lymphadenectomy. Deep dissection in this area during laparoscopic herniorrhaphy is unnecessary and risks vascular injury. To avoid neurovascular injury during laparoscopic herniorrhaphy, however, the "triangle of doom" is an inadequate warning zone. The area just lateral to the testicular vessels or medial to the iliopubic tract contains nerves (femoral nerve, lateral femoral cutaneous nerve, and femoral branch of the genitofemoral nerve) and vessels (deep circumflex) that lie just external to the transversalis fascia [43]. When fixing the prosthesis in place, it is unnecessary and unsafe to place staples medial to the iliopubic tract in the area superior and lateral to the inguinal ring. The inferior epigastric vessels, distal portion of the external iliac vessels, and their pubic or accessory obturator branches all lie within areas that must be approached when properly stapling the

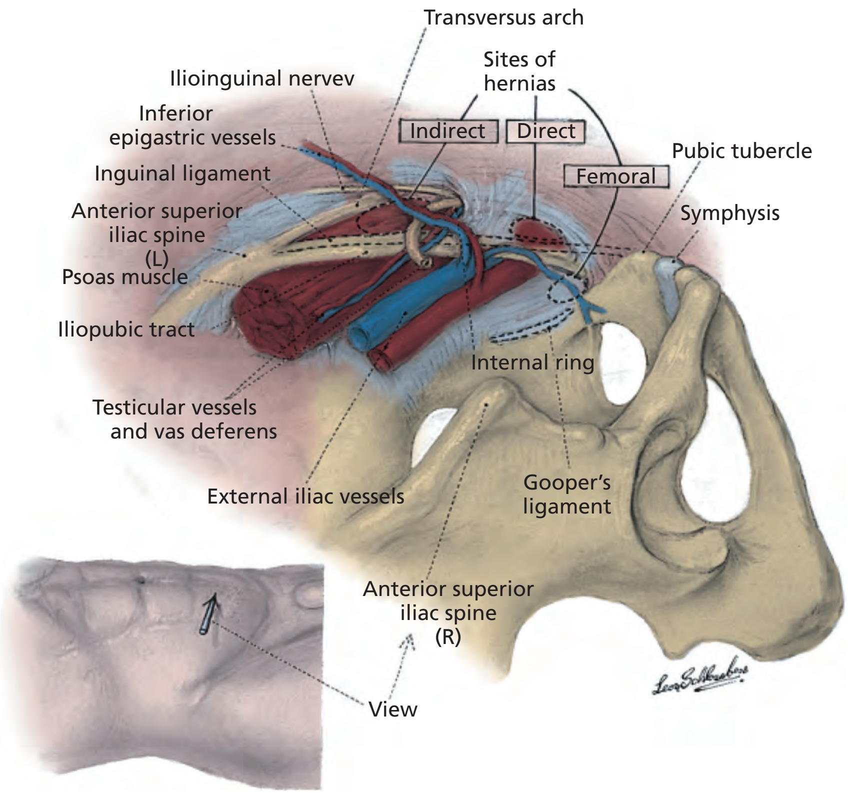
Transversus arch
Ilioinguinal nervev
Sites of hernias
Inferior epigastric vessels
Indirect
Direct
Femoral
Pubic tubercle
Inguinal ligament
Symphysis
Anterior superior iliac spine (L)
Psoas muscle
Iliopubic tract
Internal ring
Testicular vessels and vas deferens
External iliac vessels
Gooper's ligament
Anterior superior iliac spine (R)
View

Figure 95.6 Anatomy of preperitoneal structures in the left inguinal space (reproduced from Schlegel and Walsh [36], with permission).

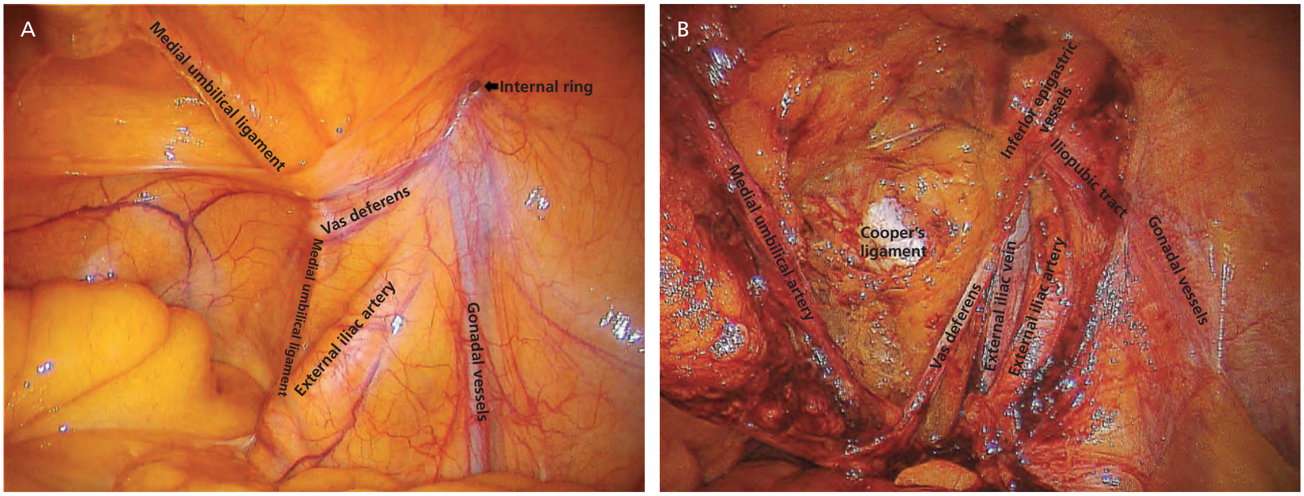
A
Medial umbilical ligament
Internal ring
Vas deferens
Medial umbilical ligament
External iliac artery
Gonadal vessels
B
Inferior epigastric vessels
Iliopubic tract
Medial umbilical artery
Cooper's ligament
Vas deferens
External iliac vein
External iliac artery
Gonadal vessels

Figure 95.7 Anatomy of preperitoneal structures in the right inguinal space from the (A) intraperitoneal and the (B) extraperitoneal perspectives.

prosthesis to the anterior abdominal wall and Cooper's ligament. Close inspection of all sites before stapling is essential.

Surgical options

Five major types of laparoscopic herniorrhaphy have been described: closure of the internal ring without prosthesis, plug repairs, intraperitoneal onlay mesh (IPOM), transabdominal peritoneal repair (TAPP), and totally extraperitoneal repair (TEP). Currently, only TAPP and TEP are commonly used.

The first laparoscopic hernia repair, performed by closing the internal inguinal ring with clips to treat an indirect hernia, was reported by Ger in 1982 [44], with a later report published in 1990 [45]. Simple suture closure of an indirect hernia defect and reapproximation of the peritoneum over the repair with clips was subsequently reported by others [46, 47]. These repairs were applicable only to indirect hernias and subsequently abandoned due to unacceptably high early recurrence rates.

The next development in laparoscopic inguinal herniorrhaphy was reported in 1989 by Bogojavlensky who placed a roll of polypropylene mesh into indirect and femoral hernia defects and closed the peritoneum over the defect [48]. Excision of the hernia sac prior to plugging of the defect with mesh was reported by Schultz *et al.* in 1990 [49]. Several other modifications to plug repairs have been described, including the application of a patch over the proximal end of the plug over which the neck of the inverted hernia sac was stapled [50], formation of the plug into a fan [51] or mushroom shape [52], attaching the patch to the plug prior to implantation [53], and suturing the aponeurotic arch to the iliopubic tract over the plugged defect [54]. Although the patch is sewn or stapled to transversalis fascia analogs in several of these repairs to improve fixation [54–56], methods incorporating a prosthetic plug have been abandoned because of high recurrence rates and migration of the plug into the inguinal canal, mimicking recurrence [43].

The remaining three techniques of laparoscopic hernia repair are based on the open preperitoneal prosthetic repair of Stoppa. The first of these techniques, the IPOM repair, was reported in 1990 when Popp described the laparoscopic suturing of the margins of a direct inguinal hernia followed by the intraperitoneal placement of a patch of dehydrated dura mater [57]. Subsequent techniques have involved the intraperitoneal fixation of a nonabsorbable prosthesis over the hernia defect [58–63]. Despite the minimal dissection required and associated decreased operative time, interest in this technique has been limited by concerns of possible adhesion formation or erosion of mesh into the abdominal viscera [43].

Currently, a popular approach to laparoscopic herniorrhaphy is TAPP. Through an intraperitoneal approach, the peritoneum is widely incised and reflected to expose the transversalis fascia analogs supporting the inguinal area. A large patch of prosthetic material is then placed overlying the medial and lateral fossae with generous overlap. The mesh is usually stapled in place, taking care to avoid nerve entrapment, after which the peritoneum is closed. The first large series describing this standard technique was reported by Arregui *et al.* [64] in 1992, and numerous publications since then attest to its popularity. The advantage of TAPP over IPOM is that the peritoneum is interposed between the abdominal contents and the prosthesis, diminishing adhesion formation [65] and presumably the risk of viscera erosion.

TEP is based on the same anatomic principles as TAPP but attempts to avoid the potential complications of transperitoneal laparoscopy. Although Popp in 1991 proposed the use of percutaneous aquadissection to help develop the preperitoneal space prior to insertion of a prosthesis transabdominally [66], McKernan and Laws [67] and Ferzli *et al.* [68] in 1992 first described a totally extraperitoneal approach in the literature. Some have reported visualizing the inguinal site from the intraperitoneal perspective while inserting and then fixing the prosthesis extraperitoneally [69, 70], while others perform the entire procedure in the extraperitoneal space [67, 68, 71–73]. The extraperitoneal space can be developed with a balloon dissector [71, 73], fluid [70], or gas [67–70, 72], with or without the use of a blunt probe [67–69, 72] to aid in the dissection. The proponents of TEP argue that the risk of intraperitoneal complications is reduced compared to the transperitoneal approach [74]. Difficulties with TEP include a limited working space and indistinct anatomic structures. The learning curve for the strictly extraperitoneal approach may be longer than for other techniques. Urologists who perform extraperitoneal laparoscopic radical prostatectomy, however, will be experienced with this approach.

Transabdominal preperitoneal herniorrhaphy

A skin incision is made at the inferior crease of the umbilicus, and pneumoperitoneum is created with a Veress needle, following which a 10–12-mm port is inserted. Alternatively, access can be obtained via the Hasson technique in the same location. After inspecting the abdominal cavity with a 10-mm, 30° laparoscope, two secondary ports are inserted, one on each side of the patient a few centimeters below the level of the umbilicus in the anterior axillary line. To facilitate insertion of the mesh, one port should be 10–12 mm in size, while the other can be 5 mm in size. Alternate port configurations include replacing the contralateral port with one in the midline half the distance between the umbilicus and pubis, or placing the lateral secondary ports lower in the abdomen.

The peritoneum is incised transversely across the anterior margin of the hernia defect(s) from the medial umbilical ligament to the anterior superior iliac spine. Care is taken to keep the incision horizontal and to not allow it to drift anteriorly. This incision will place the hernia approximately in the middle of the operative field and will allow subsequent exposure of the transversalis fascia analogs (Figure 95.8). The only significant structures crossed by the incision are the inferior epigastric vessels and the iliopubic tract. Injury to the former usually can be avoided with careful dissection. Although not necessary in most instances, these vessels can be

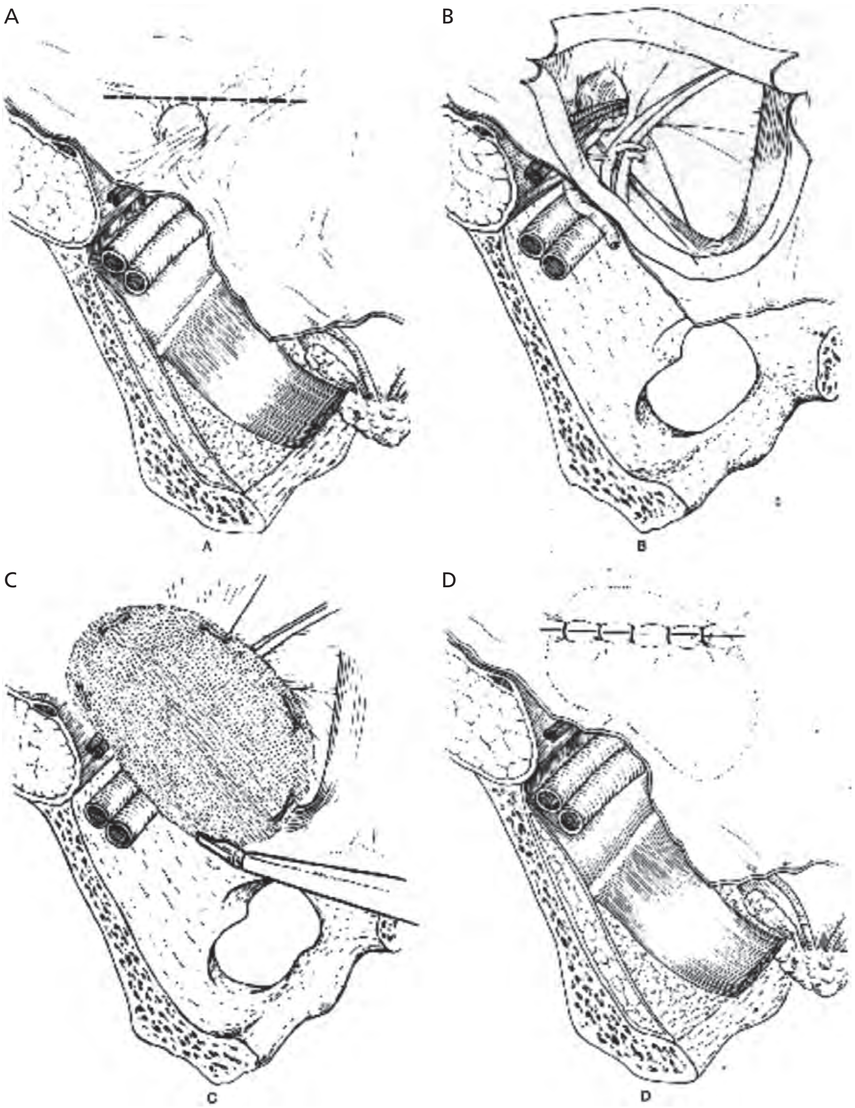

Figure 95.8 Steps in laparoscopic transabdominal preperitoneal repair of the left inguinal hernia: (A) the peritoneum is incised transversely over the hernia defect (dotted line), (B) peritoneal flaps are reflected to expose the inguinal floor, (C) the prosthetic mesh is stapled into place, and (D) the peritoneum is closed over the mesh (reproduced from Soper, N.J., Brunt, L.M., Kerbl, K. Laparoscopic general surgery. *N Engl J Med* 1994;330:409–419, with permission).

clipped and transected if troublesome. The iliopubic tract serves as an important landmark for staple placement later in the procedure.

Retracting the peritoneal edges and bluntly dissecting them free from the body wall and underlying structures develops the peritoneal flaps. If adherent areas are encountered, the surgeon can either use retraction and counter-traction by grasping the adherent band of tissue with a second instrument and separating the structures, or the band, if it is judged not to be vascular, may be transected. The vas deferens must be identified and preserved during these maneuvers if it has not already been divided during laparoscopic pelvic lymphadenectomy or radical prostatectomy. The posterior peritoneal flap is developed first. The posterior limit of the dissection is Cooper's ligament inferomedially. Superolaterally, the flap should be reflected only as far as the iliopectineal arch and testicular vessels. Next, the anterior half of the peritoneal flap is reflected. The only structures at risk of injury here are the inferior epigastric vessels, which should be left on the anterior abdominal wall. The flap should be reflected only 3–4 cm above the peritoneal incision.

A direct hernia sac, unless recurrent after a failed inguinal repair or particularly large, usually is reducible. An indirect sac is more frequently narrow and deep. If not reducible, the sac should be incised in a circumferential fashion just at or inside the neck of the sac. A wide incision might compromise later closure of the peritoneum. Dissection and attempted removal of the amputated sac are unnecessary and pose a risk of neurovascular injury. The retained sac may fill with fluid postoperatively (groin seroma or scrotal hydrocele), but the collection usually resolves within a few weeks without sequelae. The preperitoneal area that has been exposed is next cleared of fatty tissue, with special attention paid to Cooper's ligament and the iliopubic tract, which will serve as the main anchoring points of the prosthesis. Small vessels, branches of the inferior epigastric or external iliac vessels, will often be seen crossing near Cooper's ligament. These should be avoided if possible, since they may retract under the tension of the pneumoperitoneum and result in hemorrhage during attempted ligation.

The prosthetic material (usually polypropylene) is now introduced into the abdomen through one of the larger ports. A 7 × 12-cm section usually is adequate to generously cover indirect, direct, and femoral hernia sites, but the surgeon should not hesitate to use a larger piece or even two separate pieces if additional coverage is required. The mesh is inserted by rolling or folding it so that it can be passed down the port with a fine-tipped curved dissector. Once in the peritoneal cavity, the mesh is unfurled and manipulated into the preperitoneal space. A third instrument port can sometimes be useful since it can be frustratingly awkward at times to get the prosthesis into the proper position. Some surgeons incise the mesh on one side so that it can slip around the spermatic cord. Others believe that this is unnecessary and place the prosthesis over the cord.

The 5-mm hernia stapler, or tacker, is inserted through the midline or contralateral port and used to fixate the anterior edge of the prosthesis first, avoiding the epigastric vessels. A bimanual technique using the nonoperating hand to palpate the head of the stapler through the abdominal wall facilitates exact placement. Applied pressure must not be too firm or tacks will penetrate too deeply, risking nerve entrapment. Another trick is to partially deploy the tack and use one end to "hook" the mesh and then guide it into place. The superolateral tacks are placed next, extending from the upper corner of the prosthesis only as far down as the iliopubic tract. The last tack(s), placed in the iliopubic tract itself, must not be placed too deeply lest nerves become entrapped. Tacks should not be placed medial to the iliopubic tract in this location for the same reason. When applying tacks lateral to the internal ring, the surgeon must be able to palpate the stapler head through the abdominal wall to ensure that tacks are not placed posterior to the inguinal ligament. Inferomedially, tacks are placed from the corner of the prosthesis down to the pubic tubercle and Cooper's ligament. Exact visualization of the deployment of each tack also is imperative to avoid injury to vessels coursing above, below, and over Cooper's ligament and the iliopubic tract. Finally, tacks are placed in the iliopubic tract running between the inferior edge of the prosthesis and the internal inguinal ring. Again, inexact or excessively deep tack placement risks neurovascular injury.

Although fixation of the mesh is usually included as an integral step in descriptions of laparoscopic inguinal herniorrhaphy, the necessity of this step is controversial. Many surgeons feel that fixation is crucial to reducing hernia recurrence by preventing the mesh from rolling up and uncovering the hernia defect. Mesh fixation, on the other hand, has been linked to an increased incidence of nerve injury and incurs the increased cost of the tacking device (or increased costs associated with longer operative times if fixation is accomplished by suturing). Recent retrospective studies as well as prospective, randomized trials have reported no significant differences in operative time, nerve entrapment, complications, or recurrences between fixed and unfixed mesh repairs [75–77].

The intra-abdominal pressure is decreased to inspect for hemorrhage and reduce tension on the peritoneum. The peritoneal incision and any defects created during reflection of the peritoneum or incision of the hernia sac are closed over the prosthesis either with the stapler or by suturing. The staples or sutures must be placed sufficiently close together to prohibit internal herniation through the peritoneotomy.

The port sites are inspected for bleeding from the inner aspect of the abdominal wall. Ports are removed one by one under vision at 5 mmHg intra-abdominal pressure and the gas is then evacuated from the abdomen. The 5-mm skin incisions are closed with subcuticular absorbable sutures and/or sterile skin tape. The larger incisions are closed with fascial sutures, followed by skin closure.

Totally extraperitoneal herniorrhaphy

TEP starts with a small infraumbilical incision that is carried down through the anterior rectus sheath to expose the rectus muscles. The muscles are split in the midline, and gentle finger dissection creates a tunnel down toward the pubis. Inferior to the arcuate line, this tunnel becomes the preperitoneal space. Choices at this stage are to insert a Hasson-type cannula and to start insufflating with gas to open up the preperitoneal space, to dissect with a blunt probe placed through an operating laparoscope, or to use a dilating balloon to gradually lift the peritoneum off the body wall and expand the preperitoneal space. This mechanical expansion breaks strands of connective tissue that often persist when gas alone is used and will prevent full expansion of the preperitoneal space, requiring tedious dissection to transect them and allow complete visualization of the preperitoneal space. The simplest and least expensive dilating balloon is made on the operating table by tying the middle finger of a large sterile surgical glove over the end of a 16 F red rubber catheter or other available sterile tubing. Slow inflation of the balloon with approximately 1 L of saline or gas from the insufflator will safely expand the space to adequate dimensions. Alternatively, a commercially prepared dilating balloon can be purchased from one of several manufacturers. One advantage of some of the commonly available devices, the ability to look through and direct the balloon as it dilates, can be duplicated as well by the surgeon at the operating table by tying the finger of the glove over a long 10-mm laparoscopic cannula instead of a catheter. The balloon–cannula is inserted into the tunnel beneath the rectus muscles and the insufflator is connected. When the laparoscope is inserted into the balloon–cannula and the gas insufflated, the pelvic structures can be visualized through the balloon (albeit not too clearly). A final option for creation of the preperitoneal space is to insert a Veress needle, Hasson-type cannula, or dilating balloon directly into the preperitoneal space either at the hernia site or, preferably, just above the symphysis pubis. If the bladder has been drained by a catheter, as it should be prior to all extraperitoneal herniorrhaphies, the suprapubic site is fairly safe for gaining access.

Secondary ports are inserted under vision from a 10-mm laparoscope placed through the primary port as in transperitoneal procedures. The secondary ports should be placed lower down on the abdominal wall compared with placement during transperitoneal procedures to avoid violation of the peritoneum. Some authors have recommended placing all three ports in the midline: one at the umbilicus, one just above the symphysis pubis, and the third halfway between the other two. If inadvertent entry into the peritoneal cavity occurs, the gas can be allowed to escape continuously by inserting a Veress needle percutaneously into the peritoneal cavity. This will allow successful completion of the procedure in an extraperitoneal fashion if the peritoneotomy is small.

The anatomic structures are often difficult to identify from the preperitoneal perspective because the fatty and connective tissues are not uniformly compressed by a membrane (i.e. the peritoneum) and therefore obscure the distinctions that can be appreciated from the intraperitoneal perspective. Nonetheless, with continued insufflation and gentle manipulation of the peritoneum off the pelvic sidewall, the appropriate landmarks can be ascertained. The shiny white Cooper's ligament and bluish external iliac vein are often the best structures to identify first. Once oriented, the surgeon cleans off the transversalis fascia analogs and addresses the hernia sac as described earlier. Again, a deep indirect hernia sac should be amputated if it cannot be dissected easily off the spermatic cord. A significant cord lipoma should be resected to allow a better fit of the mesh around the spermatic cord.

The mesh is inserted and positioned as previously described. The same admonitions as for stapling the prosthesis during the transperitoneal procedure apply here. Always proceed with caution on the iliopubic tract and Cooper's ligament. Again, the necessity of mesh fixation is controversial.

The pneumoproperitoneum is released after removal of the ports under direct vision at a pressure of 5 mmHg, and sites are closed as described earlier.

Postoperative care

If only a laparoscopic herniorrhaphy has been performed, patients are discharged home from the recovery room unless unusual circumstances suggest the need for inpatient observation (e.g. abdominal discomfort, need for parenteral analgesics, or medically unfit for rapid discharge). An oral analgesic is prescribed routinely, although they often are used for only a few days, if at all. The patient is encouraged to resume normal activity the next day, except for heavy lifting, which is restricted for the first week. There may be some abdominal bloating after transperitoneal procedures, and an over-the-counter laxative may be helpful.

Results

A few large series on laparoscopic herniorrhaphy have been published (Table 95.3) [78–81].Operative times [78–80], morbidity, reoperation rates, and recurrence rates [81] have been shown to decrease as surgeon experience increases. The mean operative time may be as low as 30 min in experienced hands, but over twice as long for those still learning the procedure. Overall minor and major complication rates were 4.2% and 1.6%, respectively, for this series of studies. Nearly 95% of the patients underwent laparoscopic herniorrhaphy on an outpatient basis. The overall recurrence rate was less than 1%, though only two of the studies reported their follow-up time. Prolonged follow-up is necessary to determine the true rate of recurrence following laparoscopic repair.

Several randomized, prospective trials have attempted to compare the various techniques of laparoscopic inguinal herniorrhaphy with their open counterparts (Table 95.4) [82–86]. Operative times were consistently and significantly longer for laparoscopic herniorrhaphy as compared to open repair. Analgesic requirement may be lower for the laparoscopic repair as compared to open herniorrhaphy; however, there appears to be no

Table 95.3 Results of laparoscopic inguinal herniorrhaphy.

	Schwab *et al.* [78]		Schultz *et al.* [79]	McCloud and Evans [80]	Bittner *et al.* [81]	Total
Period of surgery	5/91–4/01		12/92–11/99	6/94–4/00	4/93–12/01	–
Number of patients	1388		1952	769	6479	10 588
Number of hernias	1903		2500	984	8050	13 437
Technique	1561	TEP				
	324	TAPP	TAPP	TAPP	TAPP	–
	18	IPOM				
Mean operative time (min)	75.4†		32	25 unilateral	47 unilateral	–
	33.6‡			38 bilateral	70 bilateral	
EBL (mL)	22*		–	–	–	–
Converted	17		5	3	10	35 (0.3%)
Number of complications	101		89	164	255	609 (5.8%)
Minor	83		70	157	131	441 (4.2%)
Major	18		18	7	124	167 (1.6%)
Mortality	0		1	0	1	2 (0.02%)
Admitted	79		–	39	–	118/2157 (5.5%)
Hospital stay (days)	0.07		2.1	–	–	–
Number of recurrences	11		26	8	60	105/13 437 (0.8%)
Follow-up (months)	–		39 (mean)	–	22 (median)	

†Resident as primary surgeon with attending assisting.
‡Attending surgeon only.
*n = 433.
EBL, estimated blood loss; TEP, totally extraperitoneal repair; TAPP, transabdominal peritoneal repair; IPOM, intraperitoneal onlay mesh.

significant differences in hospital stay or recurrence rates. Three of five studies found decreased convalescence in the laparoscopy group, one study was equivocal, and one study found no significant difference. No significant difference in major or minor complications were demonstrated except for the study by Tanphiphat *et al.*, which found an increased rate of postoperative parasthesia in the open repair group as compared to the laparoscopic herniorrhaphy group (33% vs 12%, $P = .008$) [82]. In addition, Lal *et al.* found that all 25 patients in the laparoscopic group reported being "very satisfied" with the cosmetic results of their surgery while only seven patients (28%) in the open group reported being "very satisfied" ($P < .001$) [86].

Most of the randomized controlled trials comparing open repair to laparoscopic herniorrhaphy involve relatively small numbers of patients, thereby lacking the power to provide statistically reliable results. To enhance the value of individual studies, a meta-analysis of the individual trials was performed by the EU Hernia Trialists Collaboration, which involved 70 investigators in 20 countries [87]. Forty-one trials were identified involving 7161 patients. Individual patient data were available for 25 trials (4165 participants). Operative times were longer for laparoscopic repairs by an overall weighted mean difference of 14.81 min (95% CI 13.98–15.64, $P < .0001$). Of 3130 laparoscopic repairs, 85 (2.7%) were converted to open, while five (0.1%) among 3541 open procedures were converted to a laparoscopic repair.

Postoperative complications were uncommon. There appeared to be fewer hematomas (8.7% vs 10.5%, $P < .01$) and more seromas (5.8% vs 3.8%, $P = 0.001$) in the laparoscopy groups. Wound or superficial infections also appeared less frequently in the laparoscopy groups (Peto's odds ratio 0.45, $P < .0001$). There were only three cases of deep infection: one case of mesh infection in each group as well as a deep infection in an open, nonmesh group. Potentially serious visceral injury or vascular injury was more common in the laparoscopy groups compared to the open groups (15 vs 5). Six of seven visceral injuries occurred in the laparoscopic groups, consisting of four bladder injuries, one small bowel injury, and one punctured stomach. A single small bowel injury occurred in the open groups. Two postoperative bowel obstructions occurred in the laparoscopic arms. Only six port-site hernias were reported.

In all trials with data, time to return to normal activity was shorter in the laparoscopy groups with a difference of about 7 days ($P < .0001$). There were also fewer cases of persisting pain 1 year following hernia repair in the laparoscopy groups (13.8% vs 19.1%, $P < .0001$) as well as fewer cases of persisting numbness (7.2% vs 13.4%, $P < .0001$).

Table 95.4 Randomized controlled trials of laparoscopic versus open inguinal herniorrhaphy.

	Taniphat *et al.* [82]			Picchio *et al.* [83]			Tschudi *et al.* [84]			Berndsen *et al.* [85]			Lal *et al.* [86]		
Enrollment period	8/92–1/96			11/96–12/97			2/93–11/94			2/93–3/96			5/00–12/01		
Technique	TAPP	Mod. Bassini	*P* value	TAPP	Lichtenstein	*P* value	TAPP	Shouldice	*P* Value	TAPP	Shouldice	*P* value	TEP	Lichtenstein	*P* Value
Number of patients	60	60		53	52		51	49		518	524	–	25	25	–
Number of hernias	60	60		53	52		66	61		518	524	–	25	25	–
Mean operative time (min)	95 ± 28	67 ± 27	.001	49.6 ± 5.4	33.9 ± 6.2	.001	87.2 ± 27.3[†] 124 ± 45.3[‡]	58.2 ± 14.6[†] 79 ± 16.6[‡]	.0001	65	55	< .001	75.7 ± 31.6	54 ± 15	< .0001
Mean hospital stay (days)	2.6 ± 1.2	3.0 ± 1.5	.10	2.3 ± 0.1	2.2 ± 0.1	.38	4.8 ± 1.6	6.2 ± 2.5	.0064	–	–	–	1.48	1.4	> .05
Analgesia	27* 22 6 3 2	18* 21 17 4 0	.016	40.4** 40.4 15.4 3.8	50.0** 30.8 17.3 1.9	.69	2.5 ± 4.4 g paracetamol 6.5 ± 11.2 mg morphine	4.6 ± 6.4 g paracetamol 19.0 ± 23.7 mg morphine	.048 .0005	4 tablets distalgesic 1st postop week	12 tablets distalgesic 1st postop week	< .001	2.6 tablets Voveran (50 mg)	5.76 tablets Voveran (50 mg)	< .001
Return to work (days)	14	15	0.14	6.1 ± 0.1	6.5 ± 0.2	< .03	–	–		10	14	< .001	12.8 ± 7.1	19.3 ± 4.3	< .001
Return to full activity (days)	28	35	0.25	45.5	42.7	0.04	24.3 ± 14.5	41.7 ± 28.7	0.0003	–	–	–	–	–	–
Recurrences (%)	1.7	0	1.0	–	–	–	3.0	8.2		1.2	0.6	.339	0	0	–
Follow-up	32 months (mean)		–	–	–	–	4.9 years (median)			3 months		–	13 months		–

*Number of patients requiring 0, 1, 2, 3, and > 3 pethidine injections, respectively.

**Percentage of patients receiving 0, 1, 2, and > 2 doses of intramuscular diclofenac over 2 days postoperatively.

[†] Unilateral repair.

[‡] Simultaneous bilateral repair.

TAPP, transabdominal peritoneal repair; TEP, totally extraperitoneal repair.

In the laparoscopy groups, 86 (2.7%) recurrences were reported among 3138 repairs compared to 109 (3.1%) recurrences among 3504 open procedures (*P* = .16). The nature of the open repair influenced the comparative performance of both TAPP and TEP laparoscopic herniorrhaphy. Hernia recurrence was less common after laparoscopic procedures than after open nonmesh repair, but no difference was noted in comparison with open mesh repairs.

Subsequent to the above studies, a large, multicenter trial at 14 Veterans Affairs medical centers randomly assigned 1983 patients to either open mesh or laparoscopic mesh repair [88]. Recurrent hernias were more common in the laparoscopy group than in the open group (10.1% vs 4.9%), as were complications (39.0% vs 33.4%), including life-threatening complications (1.1% vs 0.1%). The recurrence rate associated with laparoscopic repair when performed by surgeons who reported having performed more than 250 laparoscopic repairs was less than half that of surgeons who had performed 250 or fewer. For open repairs, there was no significant difference in the rate of recurrence between the most experienced surgeons and those with less experience. Patients treated laparoscopically reported less pain on the day of surgery and at 2 weeks. The time to resumption of daily activities was shorter for those patients undergoing laparoscopic repair (median time, 4 days for laparoscopic repair vs 5 days for open repair).

Complications

General laparoscopic complications are reviewed in Chapter 101 and will not be covered here. A number of complications relatively specific to laparoscopic abdominal wall herniorrhaphy are described below.

Hematoma, seroma, and hydrocele

Diagnosis

Postoperative swelling in the groin, scrotum, or abdominal wall may represent hematoma, seroma, hydrocele, or early hernia recurrence. Subcutaneous fluid collections may be noted within a few days postoperatively, but collections deep to the abdominal fascia may not become apparent for a week or more. Hematomas may be painful and tender or may become firmer with time. Erythema, tenderness, and fluctuation should prompt the consideration of infection.

Etiology

Undetected or inadequately addressed laceration of abdominal wall vessels (inferior epigastric, circumflex iliac), inguinal–pelvic vessels (deferential, gonadal, external spermatic, cremasteric, obturator, external iliac), or their branches may produce hematomas. Interrupted lymphatics combined with postsurgical inflammatory processes or a retained hernia sac predispose to seromas and hydroceles. Gentle tissue handling minimizes these complications.

Prevention

Larger vessels are avoided with careful dissection. Risk of undetected vessel trauma, which may lead to postoperative hematoma formation, is minimized by limiting dissection of the hernia defects and cord structures. Mobilization of deep or large hernia sacs offers no therapeutic advantage.

Treatment

Conservative management is usually sufficient as uninfected fluid collections will likely resolve. In the event of disabling symptoms or suspected infection, operative drainage may be required. If the fluid contains bacteria and is isolated from the mesh, antibiotic therapy and percutaneous drainage are indicated. If the fluid is infected and in contact with the mesh, open exploration and removal of the mesh is indicated.

Infection of the prosthesis

Diagnosis

Erythema, tenderness, swelling, warmth, and fluctuance are the usual external signs of localized infection. Pain, fever, malaise, gastrointestinal disturbances, and leukocytosis may be the presenting signs if a deep abscess forms. Aspiration with microscopic and bacteriologic examination is indicated if infection is suspected.

Etiology

A prosthesis may become infected during manipulation or subsequently from direct or hematogenous spread.

Prevention

Although there are no specific data regarding mesh herniorrhaphy, the Infectious Diseases Society of America lists procedures that include the implantation of permanent prosthetic materials under the category “moderate evidence to support a recommendation for use” of surgical antimicrobial prophylaxis [89]. Broad-spectrum intraoperative antibiotic coverage of both skin and enteric organisms, such as a second-generation cephalosporin, is recommended. The usefulness of continuing antibiotic administration postoperatively is doubtful. There is disagreement as to the need for antimicrobial prophylaxis to prevent hematogenous seeding during later invasive procedures (dental procedures, endoscopy, etc.) in a patient with an implanted prosthetic mesh.

Treatment

Incision and drainage with removal of the prosthesis are required.

Bowel adhesion to the prosthesis and bowel obstruction

Diagnosis

Abdominal pain, abdominal distention, and gastrointestinal disturbances are the signs associated with bowel adherence to the mesh with subsequent bowel obstruction.

Etiology

Most experimental evidence in animal models suggests that bowel adhesion to the prosthesis is most likely to occur after intraperitoneal herniorrhaphy and least likely to occur following TEP [90, 91]. Although PTFE is generally thought to incite less tissue reaction than polypropylene, one group found no difference between the two materials when placed intraperitoneally in a pig model [92]. However, adhesions in experimental animals after transperitoneal prosthesis placement, when they do occur, appear flimsy and do not involve the bowel [90, 91, 93]. Clinical experience suggests that this complication is unusual in humans.

Prevention

Based on the experimental findings noted above, careful closure of the peritoneum over the hernia defect is advised, if possible.

Treatment

Repeat laparoscopy with visualization of the repair site is appropriate for the patient who does not respond to a course of conservative management with intravenous hydration, bowel rest, and nasogastric suction. This will allow diagnosis of the cause of the bowel obstruction. Laparoscopic adhesiolysis may be considered, but open laparotomy is advised if there is any question of the ability to safely identify and manage the problem laparoscopically.

Nerve entrapment

Diagnosis

Pain due to nerve entrapment may be constant or intermittent, dull or sharp, burning or tingling. Hip flexion often diminishes the pain. There may be pain over the actual site of injury, and a light tapping at this site may cause an “electric” sensation down the course of the nerve [94]. Pain may be noted immediately after surgery or may become apparent over the next few weeks.

Etiology

A number of nerves are at risk for entrapment injury during laparoscopic herniorrhaphy, including almost any branch of the lumbar plexus. Entrapment most commonly involves the lateral femoral cutaneous nerve (causing meralgia paresthetica) or femoral branch of the genitofemoral nerve [94, 95]. These injuries occur when staples are placed medial to the iliopubic tract in the area lateral to the testicular vessels. Staples placed too deeply (through the transversalis fascia analogs into the internal oblique musculature) around the internal inguinal ring can entrap the ilioinguinal nerve, iliohypogastric nerve, and genital branch of the genitofemoral nerve [94].

Prevention

Careful staple placement, not using excessive pressure when firing staples into the abdominal wall, and avoiding the area medial to the iliopubic tract and lateral to the testicular vessels will prevent nerve entrapment. As discussed above, some surgeons have abandoned mesh fixation altogether.

Treatment

With analgesics and avoidance of activities that exacerbate the symptoms, most problems will resolve within 6 weeks. Local injections of anesthetics and corticosteroids may be helpful. If the symptoms persist beyond this period, laparoscopic removal of the offending staples may provide relief. If the duration since herniorrhaphy is prolonged (>3 months), neurolysis or neurectomy may be required since perineural fibrosis complicates the condition and may preclude resolution by staple removal alone [94].

Testicular pain or atrophy

Diagnosis

The complaint of a painful scrotum should prompt an evaluation with a careful physical examination and urinalysis. Suspected epididymitis should be treated appropriately. Testicular torsion is unlikely in this setting but must be considered, especially if the onset of pain is acute.

Etiology

Neurovascular injury during manipulation of the spermatic cord or indirect hernia is presumably the cause of postoperative testicular complications.

Prevention

Avoiding unnecessary manipulation of the cord structures and indirect hernia sac will reduce the incidence of testicular injury.

Treatment

If infection and testicular torsion appear unlikely, then scrotal support and oral anti-inflammatory medication can be offered to provide symptomatic relief since the testicular pain will likely spontaneously resolve over the course of 1–2 weeks. Testicular atrophy is a potential complication of any hernia procedure and the patient should be counseled accordingly during the preoperative visit.

Internal herniation

Diagnosis

The patient will present with signs and symptoms of bowel obstruction.

Etiology

Failure to adequately close the peritoneum over the prosthesis during transperitoneal herniorrhaphy may allow bowel to slip through the peritoneotomy and produce obstruction [96, 97]. Herniation of bowel through the larger trocar sites is more common.

Prevention

Careful closure of the peritoneal defect and ensuring that each staple has a generous bite of tissue should prevent internal herniation. Similarly, fascial closure of larger port sites must be secure.

Treatment

Laparoscopy or laparotomy, as described earlier, will allow surgical correction of the problem. The repair can be left intact underneath the repaired peritoneal defect. Likewise, for a port-site hernia, the bowel contents are laparoscopically reduced and the hernia site closed by intracorporeal or extracorporeal suturing techniques.

Inguinal hernia recurrence

Diagnosis

A groin mass should be considered to be an inguinal hernia recurrence if there are no signs of infection and the mass is pulsatile with a Valsalva maneuver.

Etiology

Most recurrences of inguinal hernias following laparoscopic repair early in a surgeon's experience have been attributed to the use of prosthetic mesh of inadequate size.

Prevention

A sufficiently large piece of mesh should be used to cover all potential sites of herniation with generous overlap. A 7 × 12-cm piece of mesh is recommended as the minimum size for laparoscopic herniorrhaphy.

Treatment

Several authors have reported successful repeat laparoscopic herniorrhaphy following a recurrence. The urologist performing laparoscopic herniorrhaphy should refer a patient with a suspected recurrence to a general surgeon.

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CHAPTER 96

Laparoscopic and Robotic Pyeloplasty in Children

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Introduction

Pyeloplasty may represent the ideal pediatric urologic operation to be performed with laparoscopic techniques as the morbidity of the access is greater than that of the procedure. Reducing the access-related morbidity should provide a clinical improvement and to date, this appears to be the case. Laparoscopic pyeloplasty for pediatric applications, however, continues to evolve and is not yet the new gold standard. Indeed, it will be difficult to replace the current gold standard, open pyeloplasty, from an efficacy standpoint, with 97% success in most applications. Laparoscopy has shown equivalency, but in limited studies and with limited follow-up. There is certainly strong reason to believe that it can be equally effective and with less morbidity than open surgery, with continued advances in laparoscopic and robotic surgical technology. Nonetheless, it still remains to be clearly confirmed that laparoscopy can substitute for open surgery. For now, utilization of conventional and robotic laparoscopic technique are continuing to grow for pediatric pyeloplasty and this chapter will review the strategies, techniques, and outcomes of these methods, as well as discussing reoperative pyeloplasty for those in whom surgical success has not been achieved.

Background

Laparoscopic pyeloplasty was first described concurrently by Kavoussi and Peters [1] and by Schuessler *et al*. in 1993 [2]. Pediatric pyeloplasty in a 7-year old was reported by Peters *et al*. in 1995 [3]. There was slow application of the technique with isolated case series [4]. Several variations were tried to limit the need for intracorporeal suturing, which was the major technical challenge. Application of conventional laparoscopic pyleoplasty has been limited. Robotic technology has broadened the application of minimally invasive pyeloplasty and more rapid diffusion has followed. Subsequently, several series have reported very good outcomes, equivalent to open surgery, with robotic pyeloplasty. It should be noted that comparisons with laparoscopic pyeloplasty by those performing conventional laparoscopic pyeloplasty showed no major advantage to the robotic technology [5]. For those with advanced laparoscopic skills and without access to the current robotic systems, conventional laparoscopic pyeloplasty remains an established technique for treating ureteropelvic junction obstruction (UPJO) in children.

Indications

The indications for laparoscopic pyeloplasty, by any method, are identical to those for open pyeloplasty. These should not be anticipated to change significantly, as this procedure, even when performed with minimally invasive techniques, is still a significant operation. These indications in the asymptomatic child, particularly the infant, remain controversial. A significant decline in relative uptake on diuretic renography is usually taken

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as a clear indication for surgery, as is increasing hydronephrosis. Whether a kidney that is contributing significantly less than its nonhydronephrotic mate at initial evaluation should undergo pyeloplasty remains highly controversial. Our practice is to recommend surgical intervention for severe hydronephrosis when initial uptake is less than 40%, there is a decline in relative uptake or an increase in hydronephrosis on follow-up, or if there is no improvement in the severity of hydronephrosis by 12–18 months of age.

In the symptomatic older child with hydronephrosis and lateralizing pain, with or without confirmation on diuretic renography wash-out times, surgical intervention for UPJO is appropriate. It is rarely needed to preplace a ureteral stent, and this may induce significant edema. Baseline assessment of relative renal uptake or function is useful to permit assessment of postoperative response.

The indications for reoperative pyeloplasty are much more subjective and may include pain, and persisting or worsening hydronephrosis or diuretic renal scan parameters. There is some value in an attempt at ureteral balloon dilation and stenting for 4–6 weeks, although there are few data to clearly indicate a definitive approach. This is likely due to the obvious fact that these patients are very individual.

The options of open, laparoscopic, and robotic approaches should be discussed with the family. If the family requests open surgery that choice should be honored, but this as yet has not occurred in our experience. The decision to pursue laparoscopic versus robotic pyeloplasty is based on availability of equipment and surgeon preference, as well as skill set.

Patient preparation

For all laparoscopic approaches, we have used a liquid diet for 24 h prior to surgery, and a single rectal suppository or oral bowel stimulant to clear the colon. This will facilitate operative exposure and postoperative comfort. Patients are given a preoperative dose of antibiotics and the family is consulted as to the choice regarding a preplaced or antegrade intraoperative stent. The preplaced stent is positioned with a retrograde pyelogram that offers a radiographic image of the ureter. While this is uncommonly useful, it may provide information to adjust the surgical approach. If there has been no imaging of the ureter, this is sometimes of value. The stent is then positioned optimally just below the UPJ under fluoroscopic guidance. This leaves the pelvis dilated to facilitate operative exposure (Figure 96.1). The distal coil of the stent is positioned in the bladder. An extraction string is left in place and secured to the perineum.

Stent sizing is based on age, using the formula of age plus 2 in centimeters for length. We use a 3.8F stent for children aged 3 months to 3 years, 4.7F for those aged 3–12 years, and a 6F stent for adolescents.

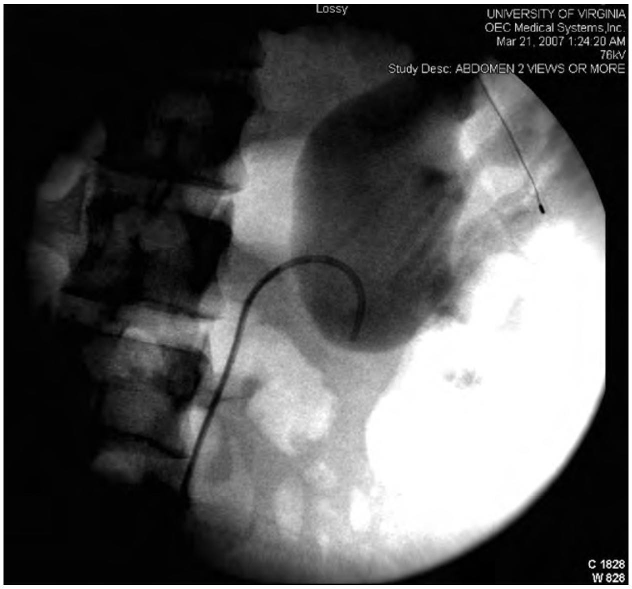

Figure 96.1 Double-J ureteral stent positioning prior to pyeloplasty. The curl of the stent is placed just below the ureteropelvic junction to allow it to be moved into the pelvis at the time of surgery, while maintaining renal pelvic distention, which facilitates exposure. An extraction string is left on the distal end of the stent to permit easy removal postoperatively (2 weeks postoperatively).

The patient is then positioned with a Foley catheter in place in a supine fashion for preparation.

Operative set-up

For both conventional laparoscopic and robotic pyeloplasty, the patient is positioned in the supine position for transperitoneal surgery. The ipsilateral side is elevated with a wedge or gel roll, the arm is braced alongside the body, and both arms are secured by a folded towel passed behind the patient and taped over the arms to the table (Figure 96.2). A chest strap and upper leg strap are taped in position as well to secure the child. The strapping is tested by rolling the patient prior to draping. Head position may need to be secured. Working closely with the anesthesia team is important in this. An orogastric tube is always placed. The patient is prepped over the entire abdomen from pubis to xyphoid.

Procedure

The basic procedure of a dismembered pyeloplasty (Anderson–Hynes) is identical for both robotic (illustrated) and conventional laparoscopic approaches. Alternative methods, although not practiced by us, are used and should be familiar to the reader.

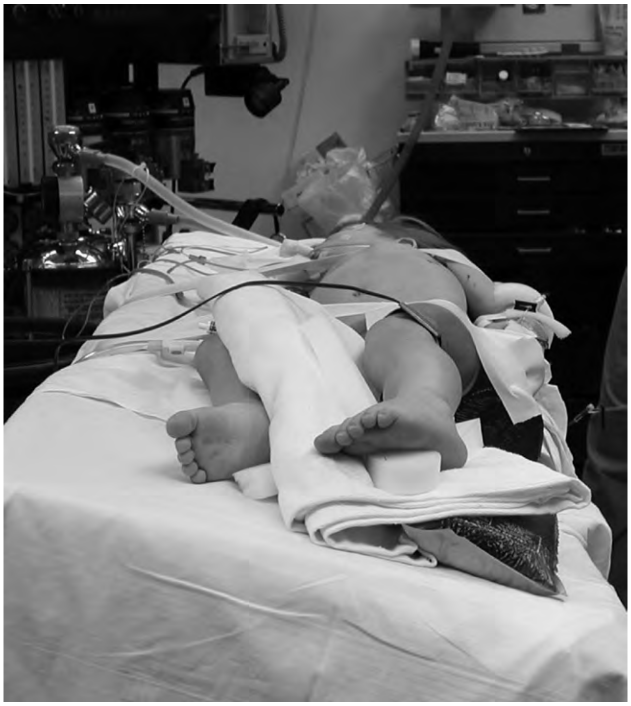

Figure 96.2 Patient positioning for a left-sided pyeloplasty. The patient is secured to the table at the chest and thighs, with the ipsilateral flank raised 30° on a wedge. By rotating the table, the patient may be oriented flat to the floor for port placement, then with a steep tilt in the opposite direction to facilitate exposure of the pelvis and kidney.

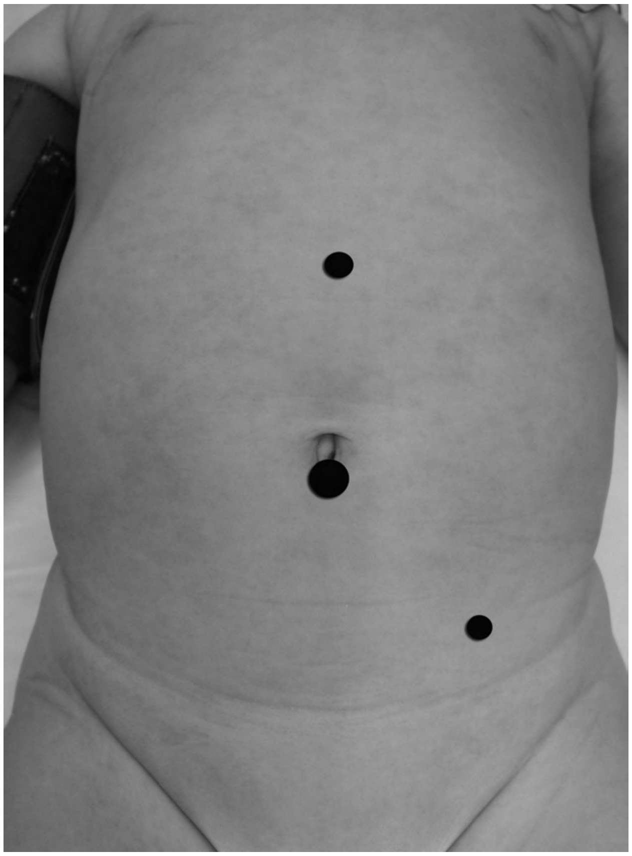

Figure 96.3 Port placement for a left-sided pyeloplasty. In small children or those with a very severe hydronephrosis in which the ureteropelvic junction is lower, the inferior port should be moved more medially and inferiorly.

Conventional laparoscopic pyeloplasty

Transperitoneal laparoscopic pyeloplasty is performed using three ports. The endoscope is placed through the umbilicus, and two working ports are placed in a symmetric array, with one in the midline between the umbilicus and the xyphoid, and the second in the midclavicular line halfway between the umbilicus and the pubis. In smaller children where the UPJ is lower, the inferior working port should be placed inferior and medial to avoid being too close to the anastomotic area. This is particularly true of the robotic system (Figure 96.3).

Port placement is performed using an open technique where the inferior edge of the umbilicus is incised in a curvilinear fashion and the tissues dissected with cautery until the peritoneum is entered. This is usually readily apparent. At this point a box stitch is placed in the fascia to ensure a tight seal and permit rapid closure at completion [6]. The camera port is then placed. In robotic cases, this is the 12-mm binocular endoscope and for conventional cases a 3.5- or 5-mm endoscope. The abdomen is insufflated. We typically use 10–12 mmHg pressure.

Working ports are placed under direct vision with preplaced fascial box stitches in the fascia. For this we typically use 3-0 Vicryl on a CT-2 needle that is bent sharply to recreate a UR-6 needle curve. For older patients, a 2-0 suture with a UR-6 needle is used if available. This approach to port placement is used in all access for laparoscopic or robotic cases.

The degree of patient tilting is determined by direct inspection with the ports in place. The dilated renal pelvis is often visible on the left side through the mesentery and the optimal position is such that the small bowel falls away yet the left colon does not fall over the pelvis. This is usually about 45° and on the right, slightly steeper angulation is usually needed to expose the pelvis. On the right, the hepatic flexure is mobilized to reveal the pelvis and the duodenum may need to be mobilized slightly. On the left, a transmesenteric exposure is preferable but not always possible. If the pelvis is not visible through the peritoneum and the upper ureter readily identified, then a retrocolic approach is best performed. The splenic flexure is released and the colon is mobilized medially from the flexure to the iliac vessels. This offers an excellent view of the kidney and pelvis.

Once the pelvis is exposed (Figure 96.4), the proximal ureter is mobilized to permit pyeloplasty, but also to limit any devascularization. The periureteral adventitia is maintained and this usually provides adequate mobilization. On the left side, when a transmesenteric approach is used, the pelvis is mobilized similarly, but very little other tissue is moved. A hitch stitch is placed at this time to permit lifting and stabilization of the UPJ and proximal ureter. This is placed by passing a 3-0 needle with a monofilament suture through the abdominal wall and then through the pelvis. It is then passed back through the abdominal wall, lifted to the appropriate tension, and fixed. This provides stabilization of the anastomotic site, exposure, and lifting of the anastomotic area away from the pool of urine and blood. The degree of tension may be altered during the procedure as needed.

The pyelotomy is performed in order to have a dependent lower vertex of the pelvis that will be sewn to the inferior aspect of the ureteral spatulation (Figure 96.5). This should be the most dependent portion of the pelvis. The amount of pelvis removed should not be excessive, but in older children with a large pelvis, some reduction is reasonable. The portion of the lower pelvis and the actual UPJ now attached to the ureter are used as a handle for manipulation to avoid any touching of the anastomotic area (Figure 96.6). The ureter is spatulated on the lateral aspect until the normal ureter is encountered, which usually opens widely (Figure 96.7).

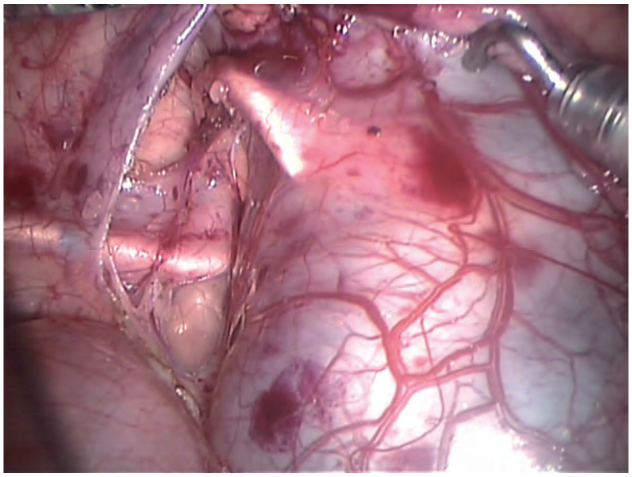

Figure 96.4 Laparoscopic view of the double-J sent at the ureteropelvic junction, just below the dilated pelvis.

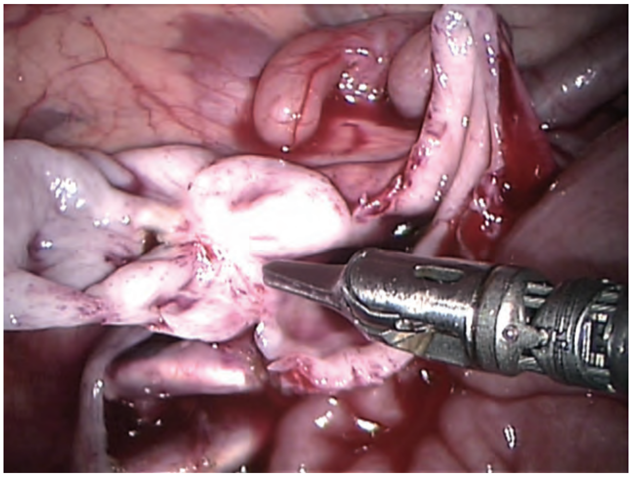

Figure 96.6 Completion of the pyelotomy, exposing the stenotic ureteropelvic junction at the tip of the scissors. The excised pelvis is used as a handle to permit control of the ureter without touching the anastomotic site.

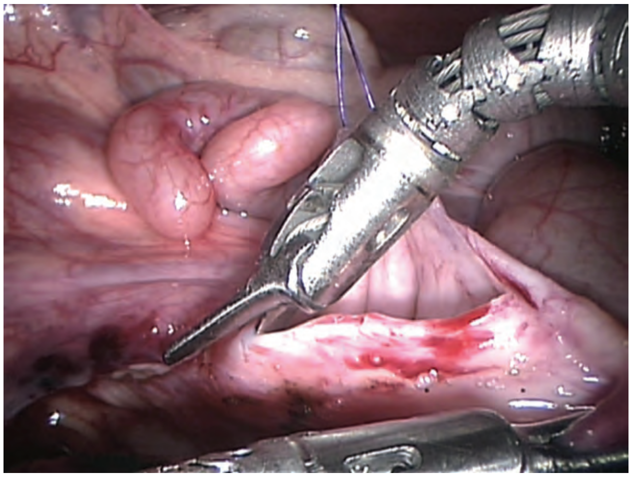

Figure 96.5 Initial pyelotomy on the anterior wall of the right-sided ureteropelvic junction. The hitch stitch is visible just behind the robotic scissors (5 mm).

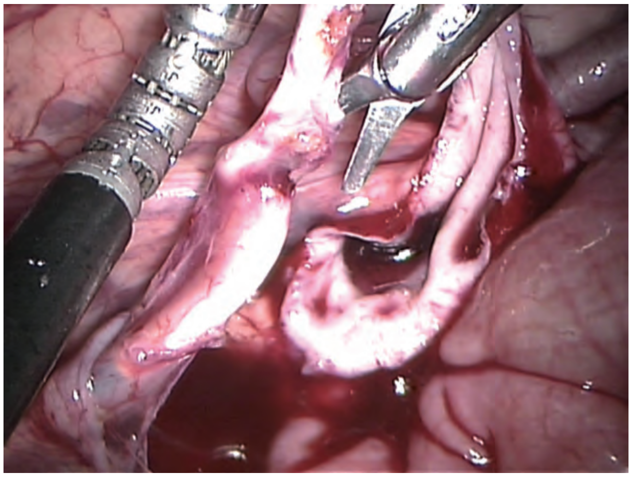

Figure 96.7 Spatulation of the lateral aspect of the proximal ureter through the stenotic segment until the ureter opens freely.

The anastomosis is begun at the inferior aspect of the spatulation and the inferior most aspect of the renal pelvis (Figure 96.8). Care is taken in placing this stitch. The posterior wall (usually) of the anastomosis is then performed with a running suture (Figure 96.9). We usually use an absorbable monofilament suture, with 5-0 used in children aged from 5 to 12 years and 6-0 for younger children. If a stent had been placed beforehand, it can be used to move the ureter around during the anastomosis, avoiding direct contact. After the back wall is completed, the stent may be placed into the pelvis, or if one has not been preplaced, an antegrade stent is placed. The handle of the pelvis and UPJ is excised (Figure 96.10).

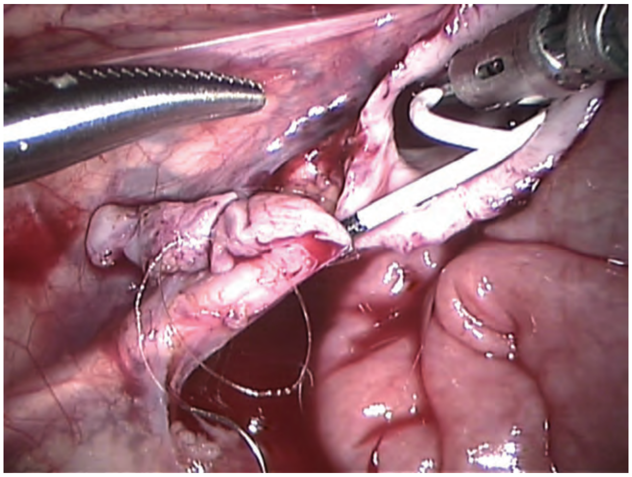

Figure 96.8 Start of the anastomosis with the initial vertex stitch placed at the inferior-most aspect of the spatulation. The anterior wall will be closed first. The choice of which wall to close first depends on the orientation of the pelvis. The stent has been moved into position in the dilated renal pelvis.

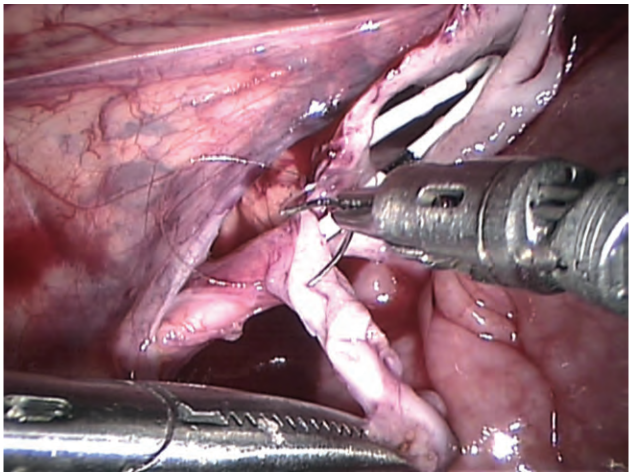

Figure 96.9 Continuation of the anterior wall closure with a running, simple suture line of 6-0 monofilament absorbable material.

Stent placement is performed by passing a 14G angiocatheter through the abdominal wall, and passing a guidewire and preloaded stent through the angiocatheter. This size will accommodate up to a 4.7F stent. If a larger stent is needed for older patients, it can be passed directly through the abdominal wall. The guidewire is passed down the ureter and the stent follows, with guidance from inside the abdominal space. Positioning is by feel and movement of the stent, as well as using rough guidelines for stent size (age + 2 in centimeters). Some authors recommend filling the bladder by clamping the bladder catheter and watching for reflux of urine through the stent, or by instilling blue dye in the bladder. Ultrasound confirmation of stent position is also suggested. We have not found these measures to be necessary.

Following stent placement, the opposite wall of the anastomosis is completed (Figures 96.11–96.13). Some

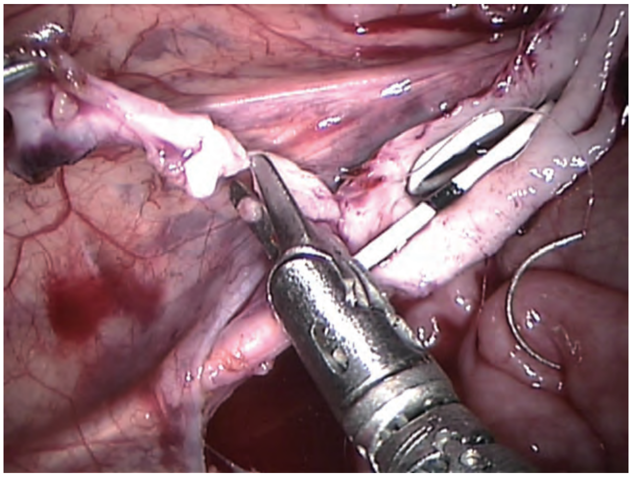

Figure 96.10 After the anterior wall is nearly completely closed, the extrarenal pelvis is excised.

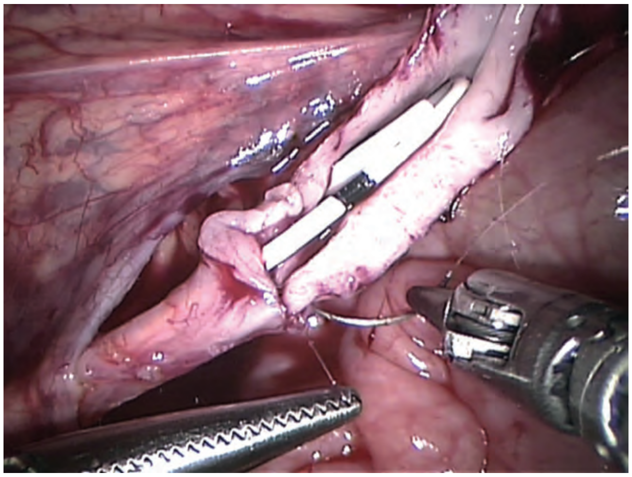

Figure 96.11 Start of the back wall closure.

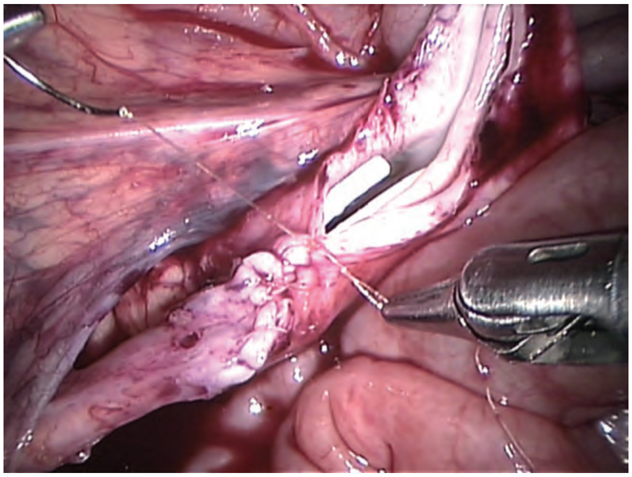

Figure 96.12 Completion of the ureteral-to-pelvic anastomosis.

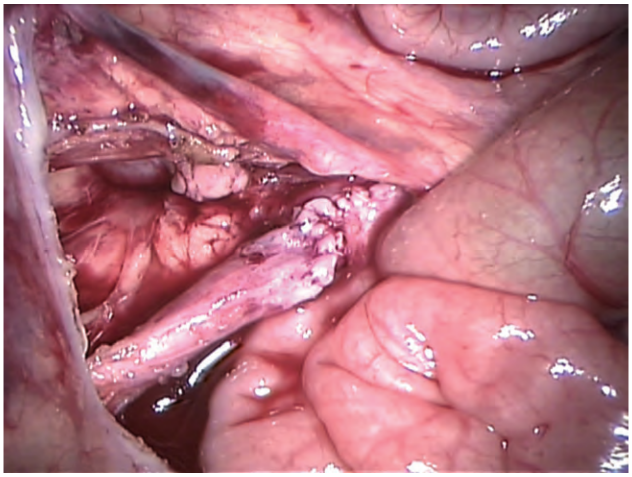

Figure 96.13 Closure of the pyelotomy is now complete.

have suggested testing the integrity of the anastomosis, but it should be recognized that an acutely water-tight anastomosis is unrealistic and testing seems unnecessary [7]. With adequate drainage, this approach heals well. No wound drain is used as long as the stent is in place, and the Foley catheter is left in place overnight.

If the stent cannot be placed, the options are to leave a perinephric drain, positioned posteriorly, or to place a nephrostomy. We have not found the latter to work well, as it can be both difficult to place and does not drain well. If the anastomosis was technically successful, a simple wound drain would seem reasonable. There have been reports of routinely not using a stent, and it is clear that this can be successful, yet seems to be an unnecessary risk when modern stents are well tolerated and seem to be generally free of problems, as compared to the potential issues when they are not used, including the need to urgently drain a urinoma or place a percutaneous nephrostomy. With stents placed retrograde in over two-thirds of pyeloplasties, permitting simple string extraction, there is little ground to argue for taking the extra risk of performing these repairs without a stent.

Robotic pyeloplasty

Robotic pyeloplasty is performed nearly identically to conventional laparoscopic pyeloplasty, using a transperitoneal approach [8]. Retroperitoneal pyeloplasties have been performed and a large series has been reported with good outcomes [9]. The youngest child reported was 1.7 years. The overall conversion and complication rate was higher than in most reports. One of the issues of note for retroperitoneal pyeloplasty has been the potential to miss the presence of an anterior crossing vessel and subsequent persisting obstruction.

We have used a three-port technique consistently and with a hitch stitch can avoid the need for a fourth port for exposure of right-sided operations.

The lower age limit for robotic pyeloplasty has not been defined, and in practice only newborns are not undergoing robotic repair. Given the success and feasibility of neonatal robotic procedures in general surgery [10], use of the robotic system in neonatal pyeloplasty seems reasonable.

There are no differences between management intraoperatively or postoperatively for robotic pyeloplasty and conventional laparoscopic pyeloplasty. The principle considerations are those of port placement and several aspects are critically important.

Both 5- and 8-mm working ports are currently available and, while it is preferable to use smaller ports, they are not as well suited to working inside the abdomen of a small child, given that they require a greater distance to turn. The distance inside the body is nearly twice as long as a comparable 8-mm instrument, due to the articulating mechanisms. For infants, we use 5-mm instruments, but set the port position further away from the surgical area. In small infants, this can mean moving the upper port from the midline to the contralateral side, and more importantly, the lower port moves medially and inferiorly, at times being in the midline. We have used three ports in the midline as the set-up for bilateral infant pyeloplasties and simply redocked the robot on the opposite side of the patient.

In performing the operation, care is taken with all instrument exchanges since there is some movement away from the last position and the space tolerances are small. Sutures are brought through the ports, and the 5-mm cannulas can accommodate 5-0 sutures on fine needles. The needle is brought in using a conventional laparoscopic instrument grasping the suture, not the needle. Alternatively, the needles may be passed directly through the abdominal wall in small children. Irrigation is performed using one of the working arms and a conventional laparoscopic suction device with the patient-side assistant controlling movement.

Vascular hitch procedures (Hellstrom)

An alternative approach to correcting UPJO associated with a lower pole crossing vessel is the vascular hitch or Hellstrom procedure [11]. In cases where the UPJO is associated with a crossing vessel that appears to be the cause of the obstruction, mobilizing the renal pelvis inferiorly and wrapping the vessel in the pelvis above the anatomic UPJ can successfully relieve the obstruction. Although introduced many years ago, and rarely performed with open surgery, this technique has taken on a new life with laparoscopic approaches.

At present the Hellstrom technique is being used in cases where there is a clear crossing vessel in which there is visible peristalsis after moving the UPJ away from the vessel. The ureter must appear fairly normal. The vessel is then wrapped in a sling of pelvic tissue that keeps the UPJ below the vessel. This assumes that there is no intrinsic obstructive element at the UPJ, and several reports have attempted to justify this with apparently normal pathology of the UPJ [12]. The method itself is simple and straightforward and avoids a dismembered repair.

The concerns regarding this approach are several. It is unclear if the crossing vessel has induced a change in the functionality of the UPJ and if this can be accurately recognized at surgery. We have seen several cases where the ureter appeared wide open and peristalsing, even without a crossing vessel and clear obstructive effect. Patients have also been seen who had intermittent obstruction based on symptoms and imaging, yet had no crossing vessel. This indicates that the anatomic arrangement of the UPJ can be abnormal without a crossing vessel. Therefore, the vessel may have little to do with the functional abnormality and the real pathology is not visible to the operator. The reports are of limited number and rarely indicate the denominator of pyeloplasties [11, 13]. This seems a risky approach to a straightforward problem for which there is an effective and efficient solution in a dismembered pyeloplasty.

Fenger plasty

Another alternative to the standard Anderson–Hynes pyeloplasty is the Fenger plasty [14], which is essentially a Heinecke–Mickulicz plasty of the UPJ. It is performed by incising the lateral aspect of the UPJ longitudinally and closing it transversely, opening up the narrowed UPJ. This is feasible with only a few sutures and has been described with a purpose-built endoscopic instrument [15]; yet results do not achieve the success levels of a dismembered repair [16] and there is little experience in children.

Postoperative follow-up

Postoperatively, the stent is removed at 2–4 weeks after surgery, and a renal ultrasound is performed 4–6 weeks after stent removal. If the degree of dilation is equal to or less than it was preoperatively, the kidney is rechecked in 3 months. If there is hydronephrosis greater than preoperatively and it is not massive, a follow-up ultrasound is performed in 6 weeks. This will nearly always show further improvement, often marked. If there is persisting or worsening dilation, a functional study is performed, such as a MAG-3 or even an intravenous pyelogram, to confirm some function in the involved kidney.

Complications

The most significant complication of pyeloplasty is persistent obstruction. This may be due acutely to edema or blood clot, and chronically to stenosis or kinking. Determining whether a persistently dilated kidney is still obstructed remains difficult. Persisting symptoms are a clear indication of the need for intervention, but most are without pain. If the degree of hydronephrosis in a child does not improve to a clear degree within 4–6 months, then it should be assumed that there is still obstruction. At this point the options include performing a diuretic renogram to assess function and drainage. Alternatively, a stent can be placed with or without balloon dilation of the UPJ, which is our choice. The stent is usually left in place for 4–6 weeks to provide some passive dilation. After stent removal, the kidney is reassessed with ultrasound. Persisting evidence of obstruction, either with or without symptoms, would prompt a reoperative pyeloplasty. Further dilation and stenting is probably of little value.

The other common complication associated with a pyeloplasty is persisting urinary drainage if a drain was left in place. This is not as common today as few drains are used with indwelling stents. On occasions, with a stent, the child will not void and develops urinary ascites due to backflow through the stent across the anastomosis. In such situations, a Foley catheter is replaced and left in place for 5 days to permit healing, and the child left to resume normal voiding.

Laparoscopic complications associated with a pyeloplasty are those that might affect any laparoscopic procedure, including bowel injury, adjacent organ injury, and port-site infection. The incidence is low, probably due to the excellent visibility during laparoscopic procedures in children. Nonetheless, there is a higher risk of severe injury due to the size and physical characteristics of children if care is not taken with all aspects of the procedure, including access and operative manipulation [17].

Reoperative pyeloplasty

When drainage through the UPJ is not adequate following surgical repair, reoperative pyeloplasty may be needed. Reoperative pyeloplasty has been performed in children using an identical port set-up and operative strategy as for a primary pyeloplasty [18], although in a small fraction, an alternative repair may be needed, such as a Y–V plasty when there is excessive scarring, or a ureterocalycostomy in a markedly fibrotic pelvis [19]. This is never a decision taken lightly and it must be considered very carefully. Ongoing symptoms, loss of relative function or clear increases in dilation are indications for reoperation. More difficult reasons include persistent but stable hydronephrosis and evidence of impaired drainage on diuretic renography. As noted above, a single attempt at ureteral dilation and stenting may be tried. This is successful in some patients, perhaps up to 50%, although there are no data to support this. If there is persisting evidence of obstruction, reoperation is likely the best course. Endopyelotomy has been reported as a useful measure for reoperative cases, yet our experience has been very unsatisfactory with endopyelotomy in cases of prior pyeloplasty. At present, reoperative laparoscopic pyeloplasty is the treatment of choice for persisting obstruction after pyeloplasty.

Preparation and set-up are identical to the initial pyeloplasty. Exposure of the UPJ is often difficult due to scarring, but often not as difficult in cases of prior open repair, as these are usually done retroperitoneally. Even with intraperitoneal laparoscopic approaches, the degree of scarring is often limited. In some, however, the scarring is intense and this must be anticipated. We have used a Y–V advancement approach in some cases when dismemberment is not possible. Otherwise, the UPJ is mobilized and the stenotic portion removed. A spatulated reanastomosis is performed with an indwelling stent, usually as wide as possible. This is left in place for at least 4 weeks and up to 6 weeks. No drain is left in place. These patients tend to do well, although they may remain in hospital a little longer than those undergoing routine primary repairs. Follow-up is similar.

Clinical outcomes

Multiple reports of pediatric laparoscopic pyeloplasty and a few of robotic procedures in children have demonstrated safety and efficacy, with results equivalent to open surgery. Operative times are longer, but are decreasing with experience. Success rates between 95% and 100% can be anticipated (Figure 96.14) with minimal risk of complications. There have been very few significant intraoperative complications recorded, and most are due to urine leakage and persisting obstruction [20]. There have been no randomized prospective trials to date, and this may now be difficult to accomplish [21]. There have been four studies with direct comparisons between techniques, yet all have addressed different techniques and had limited numbers [5, 8, 22, 23]. Two meta-analyses have shown equivalent results between open and conventional laparoscopic and robotic procedures [24, 25]. It should be recognized that all these assessments have been made relatively early in the development and dissemination of these procedures, and results should be viewed in this light [26].

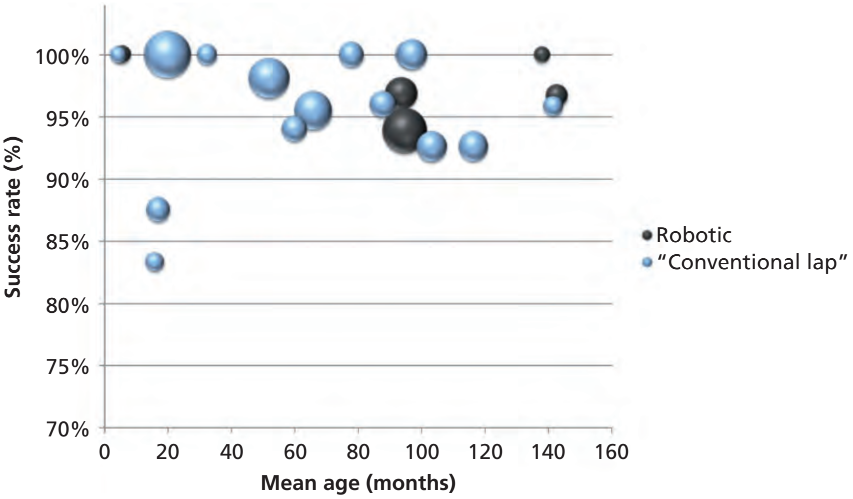

Figure 96.14 Success rates in pediatric laparoscopic and robotic pyeloplasty and mean age of patient in the reports. Patient age has no clear effect on success rate. The size of the bubbles indicates patient numbers.

Conclusions

Laparoscopic pyeloplasty has become an established aspect of the armamentarium of the pediatric urologist in some centers, while in others it remains experimental. With robotic technology the ability to accurately and effectively perform this procedure has become more accessible, and it has become more widely used. The specific advantages may be difficult to confirm in small children, but the older child and certainly the adolescent recovers more rapidly than with open surgery. Most may be discharged on the first postoperative day. While some surgeons will therefore limit its use to those over a certain age, we use robotic technology in all pediatric patients undergoing pyeloplasty except for the rare newborn, and even this is not a strict distinction. If there is a discernable benefit for the older child, there is likely a benefit for an infant, even if we are not able to discern the benefit using current methods. The operative visibility and the rapid recovery characteristic of laparoscopic and robotic pyeloplasty argue strongly for minimally invasive pyeloplasty in all children. Continued efforts to enhance the operative methods, the intraoperative manipulation, and the means to assess perioperative morbidity will help in determining the ultimate role of these new technologies in pediatric care.

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CHAPTER 97

Pediatric Laparoscopic and Robot-Assisted Laparoscopic Renal Surgery

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Introduction

Laparoscopy in urology may be considered to have its beginning in the field of pediatric urology. Cortesi *et al.* pioneered the use of laparoscopy as a diagnostic tool for localizing nonpalpable undescended testicles in 1976 [1]. A considerable amount has changed over the last three decades. Minimally invasive surgery in the form of laparoscopy has evolved from a diagnostic to a therapeutic and reconstructive technique. Laparoscopic renal surgery has almost become the standard in adults, while in the pediatric setting it continues to gain momentum. This chapter discusses minimally invasive renal surgery utilizing laparoscopic techniques, with and without robotic assistance, in pediatric practice.

History

Since Clayman *et al.* first described the laparoscopic radical nephrectomy (LRN) in an adult, it was inevitable the technique would be applied to children [2]. It is thought that the first LRN to be performed in a child occurred in Boston; however, the first published report of LRN in a child was performed at the University of California-Los Angeles in 1992 [3]. Shortly thereafter, additional reports describing the safety and feasibility of LRN in children appeared in the literature [4, 5]. The first published report of laparoscopic radical nephroureterectomy (LRNU) in a child was by Das *et al.* for a nonfunctioning refluxing renal unit [6]. The initial published report in 1993 of a laparoscopic partial nephrectomy (LPN) performed in a child for a ureteral duplication anomaly came from Eastern Virginia Medical School by Jordan and Winslow [7]. This same institution applied laparoscopic techniques for performing one of the earliest reported laparoscopic pyelolithotomies [8]. Renal cyst decortications, calyceal diverticulectomy, and nephropexy are additional upper tract procedures that have also been performed with a minimally invasive approach utilizing laparoscopy.

Robot-assisted renal laparoscopic surgery in children has been an area of increasing interest. The merits of the robot-assisted approach are fully realized for reconstructive procedures such as pyeloplasty or ureteral reimplantation, given the degree of motion of the instrumentation. LRN is rarely a technically complex procedure in the pediatric population and large series in the literature reporting robot-assisted LRN are lacking. One of the first pediatric robot-assisted renal laparoscopic procedures to be published was a case report of bilateral heminephroureterectomies by Pedraza *et al.* in 2004 [9]. Many of the same renal procedures described earlier without robot assistance have now been performed with robotic assistance.

Technical considerations/differences between children and adults

The technical considerations when comparing adult and pediatric laparoscopic cases translate into port sizes and an appreciation for the greater compliance of a pediatric abdomen compared to an adult patient. With

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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regard to port size, whether it is an adult or pediatric abdomen, a limiting factor will be the instrument used to address the renal hilum: If a stapling device is to be used, a 12-mm port must be placed. Depending on vessel size, 5- or 10-mm titanium or Hem-o-lok clips will require a 5- or 10-mm port, respectively. In the pediatric patient, there are instances where renal vasculature is small enough (<7 mm) that a coagulating device (i.e. 5-mm LigaSure or Harmonic scalpel) is sufficient to address the renal hilum, e.g. a nephrectomy on a nonfunctioning multicystic dysplastic kidney with atretic vessels.

Whether a nephrectomy is performed in an infant, toddler, teenager, or adult, a basic “triangulation” trocar format is utilized, with subtle modification, depending on age (Figure 97.1). More compliant abdomens of the infant, toddler, and preschool child will require a more “curved” configuration in order to maximize exposure and ergonomics during a nephrectomy (Figure 97.2).

The highly compliant pediatric abdomen (compliance = volume/pressure) limits the use of a direct visual obturator to gain access to the abdomen prior to nephrectomy as the risk for injury to other intra-abdominal structures dramatically increases (Figure 97.3). In this regard, an open Hasson or Baliez technique is always used at the umbilicus to place the initial camera port.

It is not uncommon for children to require bilateral laparoscopic procedures. In such instances, only one additional trocar and repositioning may be required (Figure 97.4).

Specimen extraction is a function of the size of the kidney and whether or not morcelation will be employed. The umbilical trocar, used for a 5- or 10-mm telescope, may be lengthened cephelad to remove a specimen. Alternatively, a separate Pfannenstiel incision can be made to extract the kidney. This suprapubic incision may have some cosmetic value in the pediatric population.

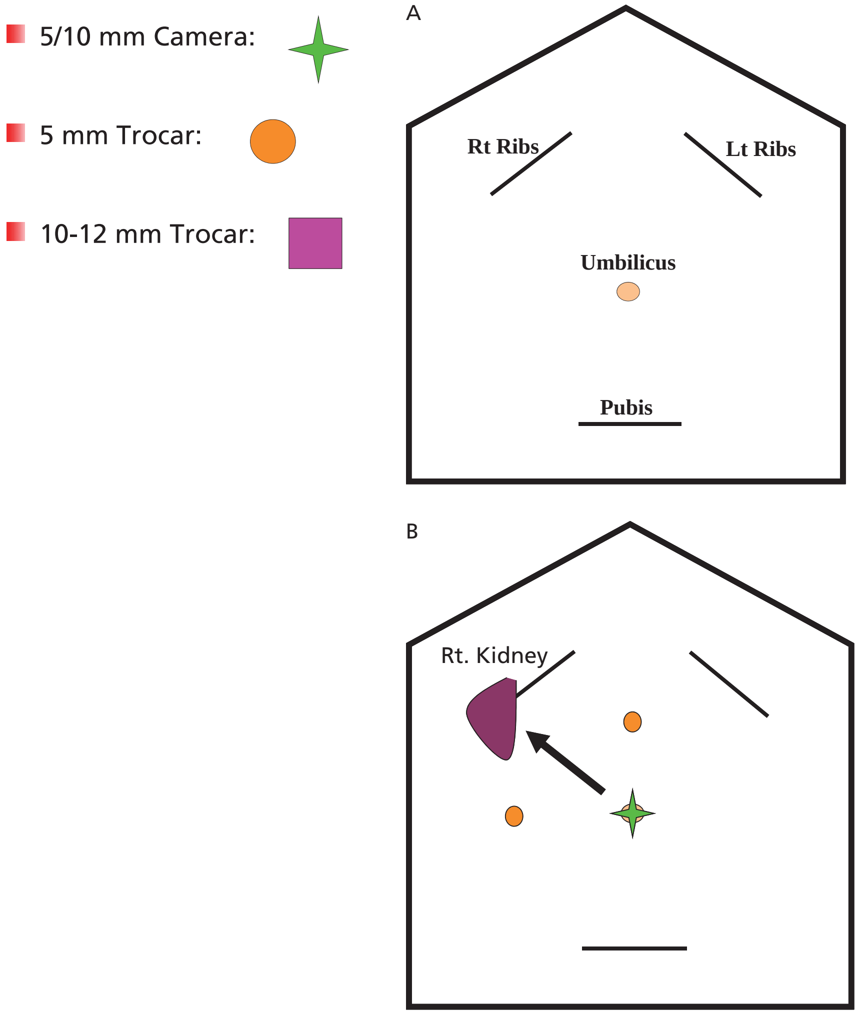

Figure 97.1 Trocar placement in renal surgery. (A) Abdominal grid and guide in adult or pediatric patients undergoing laparoscopic renal surgery. (B) Principle of “triangulation” guides port placement for laparoscopic renal surgery. Triangulation aligns the working trocars directed at the renal hilum, maximizing surgical ergonomics.

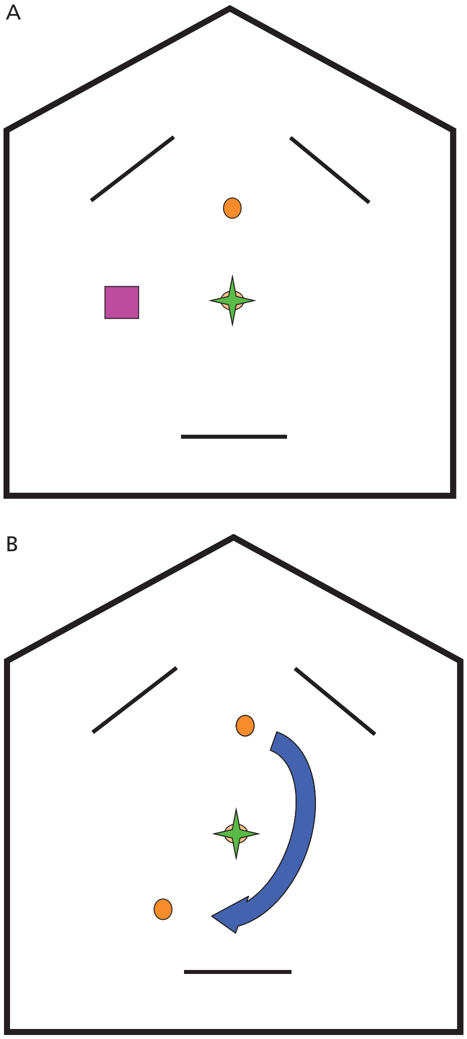

Figure 97.2 Trocar placement in laparoscopic renal surgery: nephrectomy, upper pole nephrectomy, partial nephrectomy, and pyeloplasty. (A) In the adult, the main working port is usually placed in the ipsilateral lower quadrant at the level of the umbilicus. In the case of a nephrectomy, the renal hilum is most often stapled via the 12-mm port with an endovascular stapler (60 mm). (B) In children, the "triangular" configuration is opened to give a more "curved" alignment. The right lower quadrant main working port is dropped cephalad in order to maximize working room and ergonomics. The examples are shown for right renal surgery; for left renal surgery, trocar placement would be a mirror image of this. See Figure 96.1 for key to trocar ports.

Access to the peritoneum/retroperitoneum for laparoscopic renal procedures

Laparoscopic renal surgery can be performed by either a retroperitoneal or transperitoneal approach, and this will determine patient positioning and trocar placement.

Transperitoneal approach

One of us (BV) routinely performs renal laparoscopic procedures via a transperitoneal approach because of the increased working space compared to with the retroperitoneal approach. Robot-assisted laparoscopic renal surgery needs to be accomplished via a transperitoneal approach in young patients, given the size limitations necessary to avoid robotic arms hitting one another during the procedure.

The patient is placed in a modified flank position with the surgery side rotated up by approximately 30°. A gel roll placed behind the back assists in providing this rotation. All pressure points are well padded and the patient secured to the table with wide adhesive tape across the shoulders and hips. A "test roll" is performed prior to draping by rotating the table to ensure stable patient positioning. This involves rotating the table away from the surgery side of the patient. This maneuver allows the intra-abdominal viscera to fall away from the operative field to assist in exposure. The abdomen from the xyphoid process to the mons pubis and ipsilateral flank is sterilely prepped and draped. A urethral catheter can be placed on the sterile field intraoperatively or prior to draping, depending upon surgeon preference and the procedure to be performed. Nasogastric suction can decompress the stomach prior to trocar insertion.

Pneumoperitoneum can be established via a Veress needle placed through the rectus fascia at the umbilicus or open Hasson technique. With the placement of the Veress needle the surgeon should appreciate two separate layers that represent the needle traversing the rectus sheath and peritoneum. Correct Veress needle placement in the peritoneum is confirmed by aspiration with no withdrawal of blood or fecal matter and maintenance of a low pressure (<10 mmHg) upon insufflation of CO_2. The Hasson technique involves incision through the skin and, under direct vision, the rectus sheath is opened just enough to accommodate the size of the trocar being placed. Entry into the peritoneum is performed sharply and the trocar placed into the cavity. Insufflation can begin to obtain pneumoperitoneum. Open access techniques are most often used in children to minimize the risk of abdominal organ injury.

Passeroti *et al.* have recently shown in a single institution study of over 800 pediatric urologic laparoscopic procedures that no statistically significant difference exists between the two techniques with respect to access-related complications [10]. They reported an incidence of 2.3% with a Veress needle compared to 0.8% when an open Hasson technique was utilized. The authors determined that while the overall complication rate was low in their series, surgeons who performed more than 12 laparoscopic surgeries annually had a lower

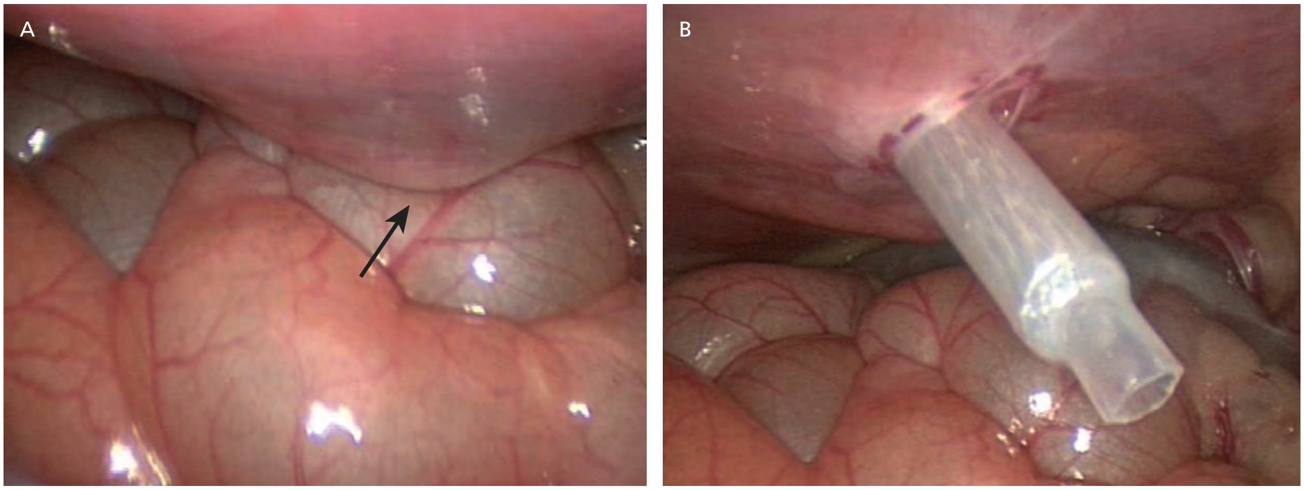

Figure 97.3 The highly compliant pediatric abdomen offers little resistance when insufflated. Use of a direct visual obturator may increase the risk for organ injury. (A) Even under direct vision, trocar placement places the anterior abdominal wall in close proximity to the bowel (arrow). (B) 5-mm dilating step trocars are most often used.

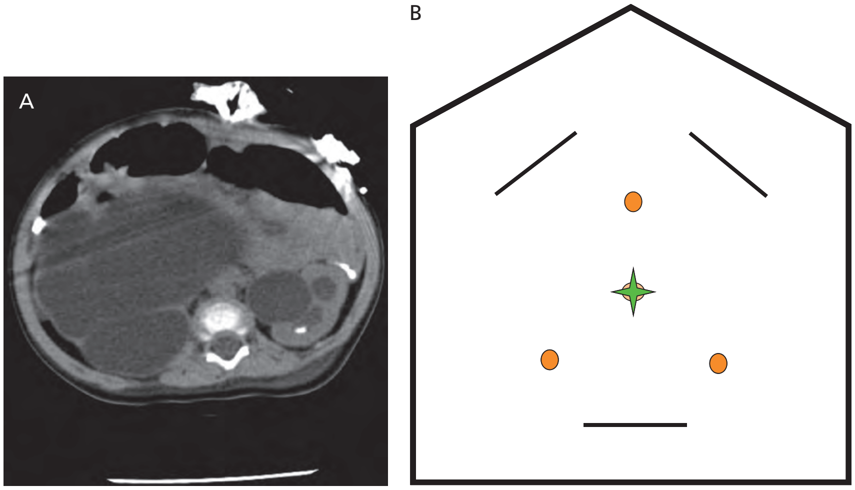

Figure 97.4 This 4-yearold boy with bilateral ureteropelvic junction obstructions (UPJOs) underwent simultaneous laparoscopic renal surgeries. A left laparoscopic pyeloplasty was first performed. Repositioning and additional placement of a right lower quadrant port (5 mm) allowed for a laparoscopic nephrectomy to be performed on a dysplastic nonfunctional renal unit resulting from a UPJO. See Figure 96.1 for key to trocar ports.

complication rate compared to less active laparoscopic surgeons.

Optical visualization during initial trocar placement can be performed when using a Veress needle. This is accomplished with a 0° lens placed through the obturator of the trocar (i.e. XCEL trocar; Ethicon Endo-Surgery Inc, Cincinnati, OH, USA) that provides a continuous ability to see through all layers of the abdominal wall while obtaining access to the peritoneal cavity. Following making a skin incision large enough for the trocar to pass easily; the lens, obturator, and trocar are inserted through the abdomen. Once entry into the peritoneal cavity is confirmed, the trocar is advanced a few more millimeters and the obturator and camera are removed. Reinsertion of the camera alone through the trocar can then allow for unimpeded inspection of the peritoneum and the path taken by the previously placed Veress needle.

Retroperitoneal approach

Advocates of the retroperitoneal laparoscopic nephrectomy cite that open renal surgery is performed extraperitoneally and that a minimally invasive technique should replicate the established technique. Additionally, with the kidney being a retroperitoneal organ, a retroperitoneal approach is the shortest distance to the kidney. Theoretically, injury to peritoneal structures should also be less with a retroperitoneal approach. The major disadvantage of a retroperitoneal laparoscopy is the limited working space relative to the transperitoneal method. Histories of prior retroperitoneal surgery or infectious process are considered relative contraindications for the retroperitoneal approach as the dense adhesions encountered in these situations hinder dilation of the retroperitoneal space.

Patient positioning can either be prone or flank when utilizing a retroperitoneal approach. The prone approach takes advantage of gravity as the kidney falls anteriorly, facilitating hilum exposure. There is also less chance for peritoneal violation with a prone approach. The flank approach provides a greater working space and slightly more access to the distal ureter. Trocar placement will differ depending upon patient position. When the patient is in the flank position, initial access can be accomplished via the open Hassan technique. An incision is typically made off the tip of the 12th rib; dissection of the flank musculature down to the lumbodorsal fascia is performed. This fascia is then opened only enough to allow for placement of a finger and the retroperitoneal space is entered. A larger incision runs the risk of air leak during insufflation of the retroperitoneal working space. Blunt dissection with the finger to create a space that can accommodate a dilating device is the next step. For the prone approach, initial access is gained with the patient in the full prone position using a subcostal incision at the edge of the paraspinous muscles and the 12th rib, and this is developed with blunt dissection through the latissimus and oblique muscles.

Expansion of the retroperitoneal space is necessary to allow for visualization of the surgical field and the addition of working ports. This is usually accomplished with a balloon inflation device, either one that is commercially available or one crafted out of a surgical glove placed over a red rubber catheter and affixed with suture. Commercially available devices will only be useful for the older patient and therefore the surgical glove technique is more commonly employed. The dilating device is placed into the retroperitoneum and filled with saline to expand the potential space. The volume of saline instilled to achieve adequate space is typically around 150–200 mL, depending upon the size of the patient. Following removal of the dilating device, a trocar can be placed into the retroperitoneum. A tight seal is created with a suture passed through the fascia and cinched up the tissue around the trocar. Alternatively, a blunt-tipped trocar (US Surgical, Norwalk, CT, USA) is used to seal the trocar site and, because of its low profile, it should not obstruct the view or working space. The retroperitoneum is then insufflated with CO_2 to allow for additional ports to be placed.

There are limited reports of the safety and feasibility of robot-assisted laparoscopic renal surgeries. The size of the robotic arms and need for adequate spacing between them makes a retroperitoneal more difficult than a transperitoneal robotic procedure.

Radical nephrectomy/nephroureterectomy

Indications

There are several indications for removal of a kidney with a partial or complete ipsilateral ureter. A nonfunctioning or poorly functioning kidney may result in recurrent episodes of urinary tract infections (UTIs). LRNU can be a highly successful procedure to eliminate subsequent UTIs in nearly all cases of a poorly functioning kidney secondary to vesicoureteral reflux. In the case of a single system kidney drained by an ectopic ureter and poor function, an extirpative approach may be preferred over reconstructive efforts. In this instance, the decision to perform a LRN alone or LRNU is left to the surgeon. The ureteral stump does carry a risk of infectious complications if retained, albeit very small. Similarly, a nonfunctioning renal unit secondary to obstruction, most commonly from ureteropelvic junction (UPJ) obstruction, can also serve as a risk factor for UTI or urolithiasis. Once again, depending upon whether the obstruction is located proximal or distal, a LRN or LRNU, respectively, may eliminate this risk.

Renal masses, both solid and cystic, have the potential to harbor malignant elements, with that risk being higher with solid masses. Certain age groups may help to predict the pathology of the mass, but surgical exploration is warranted when radiographic characteristics are ambiguous. Multicystic dysplastic kidney (MCDK) is a frequent cystic abnormality encountered by the pediatric urologist. Local symptoms such as respiratory compromise or gastric outlet obstruction have been reported due to the mass effect of MCDK, with nephrectomy alleviating these problems [11]. Many MCDKs spontaneously involute with time; however, a small percentage will enlarge over time. Extremely rare case reports of malignant elements within a MCDK can produce anxiety in both physicians and parents, which may prompt surgical intervention, although it is estimated that approximately 2000 nephrectomies would need to be performed to treat one case of Wilms tumor [12]. Originally considered a contraindication to LRN; reports of LRN for Wilms tumor have been described. Many of these LRNs are performed after neoadjuvant chemotherapy to decrease tumor size prior to surgery.

Operative technique

Transperitoneal approach

Additional working 5-mm trocars can be placed as needed. One trocar is placed in the midline beneath the xiphoid process. To complete a triangulation pattern around the renal hilum, an additional 5-mm trocar is placed lateral to the umbilicus at the anterior axillary line on the ipsilateral side where surgery is to be performed. When performing a LRNU, this lateral trocar is displaced inferiorly to make it easier to reach the distal ureter. However, in most small children, it is rare not to be able to reach the pelvis with a standard triangular port configuration. An additional modification of standard trocar placement may be necessary in the obese patient. Placement of the working trocars in a more lateral position may be advantageous as the working distance from the midline to the kidney is greater as body mass index increases.

When performing a robot-assisted LRN or LRNU, even greater attention must be given to the placement of the working trocars. This is due to the possibility of the robotic arms crashing into each other during their movement. A general rule of thumb is to place the robotic working trocars at a minimum of 8 cm from the camera to minimize the potential for this problem. Another difference between the robot-assisted approach and pure laparoscopy is that the camera necessary for robot-assisted renal surgery will need to be larger than 5-mm to take advantage of the three-dimensional (3D) imaging capabilities of robotic system. This is because smaller lenses are monocular and cannot provide a 3D image. A fourth trocar will be necessary for the bedside assistant to use laparoscopic suction or to apply clips. After placement of all trocars, the robotic device is docked from the ipsilateral side and the robotic arms are engaged. The robot has several instruments (scissors, needle drivers, and graspers) that are available in both 8- and 5-mm sizes.

Mobilization of the colon and adjacent structures that are anterior to the kidney is the first step. Incision of the white line of Toldt with mobilization of the colon medially will expose the retroperitoneum and Gerota's fascia. Identification of the ureter provides the surgeon with a familiar landmark. Anterior traction on the ureter will define the posterior limit of the dissection in the retroperitoneum. This maneuver performed near the hilum also places the renal artery and vein on stretch during their dissection prior to ligation. Safe visualization of the operative field for a left-sided LRN is usually not difficult following adequate mobilization of spleen and descending colon. However, for a right-sided LRN, the liver may obscure the operative field. A grasping laparoscopic instrument can provide anterior retraction of the liver and maintain the retraction after grasping the lateral abdominal wall. This results in markedly improved visibility, but care must be taken not to grasp the diaphragm, which may result in tear and pneumothorax. Alternatively, a 5-mm "snake retractor" may be passed through a subcostal trocar to retract the liver (Figure 97.5).

If LRN is being performed due to concern over a potential renal malignancy, the dissection should remain outside of Gerota's fascia. Following adequate mobilization of adjacent organs and with anterior traction of the lower pole of the kidney and ureter, hilar structures should be easily identified. Lateral dissection of the kidney is inadvisable at this point because the kidney will rotate after losing this point of fixation, resulting in obscuring the hilar structures upon anterior traction of the lower pole of the kidney. The renal arteries associated with MCDK are typically small in caliber, with the renal vein being of normal size. Individual isolation of the renal artery and vein is advised prior to separate ligation of the vessels with clips. A laparoscopic stapler can be used to control the renal vessels, but these devices require upsizing any existing 5-mm trocar as they will fit only through a 12-mm trocar. Following division of the renal vessels, the dissection continues along the superior medial aspect of the kidney. Adrenal-sparing LRN is performed by clear visualization of the adrenal tissue, which is sharply distinct from the now devascularized kidney. It is at this point that dissection along the lateral border of the kidney should proceed and medial traction of the kidney easily displays the proper surgical plane to follow. Aggressive dissection along the posterior aspect of the upper pole should be avoided as the diaphragm is close and there is the risk of tear. Caudal displacement of the kidney allows for identification of any remaining attachments of the kidney. These attachments should be cauterized as they often contain blood vessels because they are located near the inferior border of the adrenal gland. Once avulvsed these vessels may retract and can be difficult to find and control.

If a LRN is the only procedure to be performed, then the kidney can be separated from the ureter at this point with the specimen placed into a laparoscopic specimen retrieval bag. However, if a LRNU is to be performed, then maintaining continuity of the ureter with the kidney may be preferred, allowing for easier cephelad traction of the ureter to assist in distal dissection. Care must be exercised as the ureter crosses anterior to the iliac vasculature. In the male, knowledge of the location of the vas deferens during pelvic ureteral dissection is essential to avoid injury. For the refluxing ureter, following its division from the bladder, closure of the ureter is necessary to avoid postoperative leakage from the stump. This can be accomplished with intracorporeal suturing with absorbable suture or with an EndoLoop ligature. In contrast, most surgeons will leave a nonrefluxing obstructed ureter open after transection.

The kidney and ureter can be placed into a laparoscopic entrapment sac and removed *en bloc* or

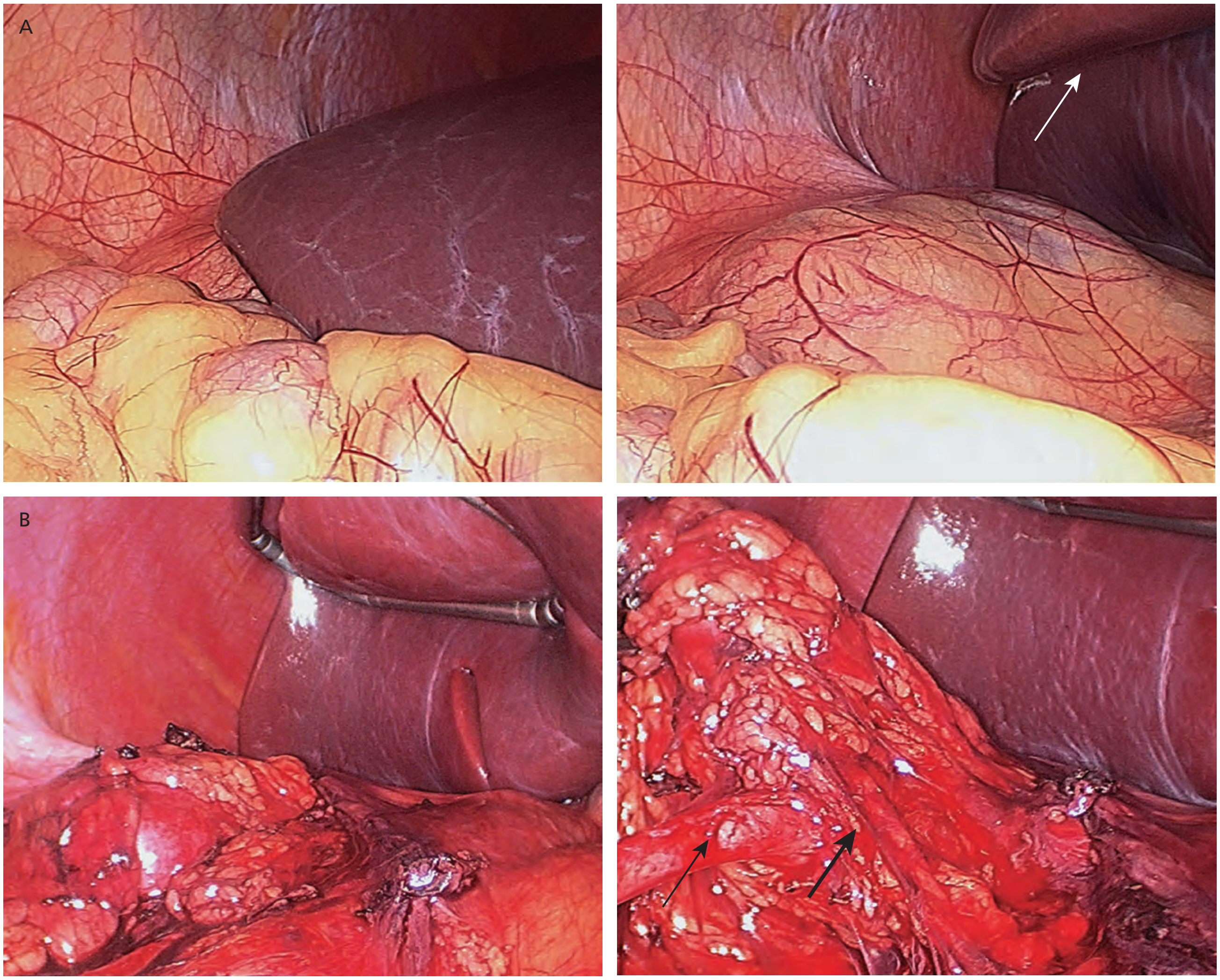

Figure 97.5 Liver retraction during right renal surgery. (A) During right laparoscopic renal surgery, the liver may often obscure and hinder dissection of the kidney (left). An additional midline trocar may be placed and an instrument can be placed to the side wall retracting the liver and sustaining it on a bridge (arrow) (right). (B) A "snake" liver retractor can also be used through a right subcostal trocar to expose the right kidney (left). View of the right ureter (thin arrow) and hilum (thick arrow) prior to nephrectomy (left).

morcellated depending upon the indication for surgery. Following removal of the surgical specimen, the operative field is inspected and hemostasis insured. Decreasing the insufflation pressure may reveal venous bleeding that is under tamponade at higher pressures. We recommend closure of all trocar sites greater than 3 mm in diameter in children. The Carter–Thomason device is especially helpful in fascial closure of the trocar sites. The skin is closed with a subcuticular suture.

Retroperitoneal approach

For the retroperitoneal flank approach, a working trocar is placed posterior to the initial incision after inserting a finger into the retroperitoneum while directing the trocar onto the tip of the inserted finger. The posterior trocar combined with a camera in the retroperitoneal space allows for the development of the space medial to the initial trocar for placement of the anterior trocars. This is accomplished using a dissector or aspirator to push the peritoneum medially, and additional trocars are placed under direct vision. This peritoneal sweeping maneuver must be performed carefully to avoid injury to the peritoneal reflection, which could result in a tear in the peritoneum, resulting in significantly reduced insufflation of the peritoneum and a smaller retroperitoneal working space. For the prone retroperitoneal approach, secondary working trocars are placed above the iliac crest just lateral to the paraspinous muscles and just medial to the peritoneal reflection.

Once all the necessary trocars have been placed, the initial step is identifying the border between the psoas muscle and lower pole of the kidney. Similar to a transperitoneal approach, subsequent identification and upward traction on the ipsilateral ureter assists in identifying hilar structures. Lateral traction on the kidney places the hilum on stretch for dissection and visualization. The renal artery is more clearly visualized with retroperitoneal laparoscopy compared to the transperitoneal approach as it is located posterior to the renal vein. Each vessel can be clipped and transected with similar methods to those described for transperitoneal laparoscopic renal surgery. Anterior dissection results in the kidney falling onto the hilum, and to maintain adequate visualization of the hilum, anterior dissection of the kidney with the flank approach should be avoided prior to transection of the vessels. Remaining perinephric attachments can be released with blunt and electrocautery dissection as previously described . The ureter is transected and the specimen placed into a laparoscopic entrapment sac. The kidney and ureter can be removed *en bloc* or morcellated, depending upon the indication for surgery. Trocar site closure is performed as previously described.

Postoperative care

The nasogastric tube placed intraoperatively is removed prior to the patient leaving the operating room. Patients can be started on clear liquids on the day of surgery and advanced to a regular diet upon return of bowel function. The urethral catheter can be removed the morning after surgery in uncomplicated LRN. Ketolorac is a very useful analgesic in the immediate postoperative period as an adjunct to the judicious administration of narcotics. Ketolorac should not be used in patients with renal insufficiency. Most patients remain in hospital for 24–48 h after surgery.

Outcomes

The safety and efficacy of LRN and LRNU for benign disease in children have been firmly established since their first descriptions [13–45]. The rate of conversion from a laparoscopic planned approach to open renal surgery is very low in published series (Table 97.1), and there does not appear to be significant disparity in conversion rates between pediatric series of LRN and LRNU. Transperitoneal or retroperitoneal approaches to laparoscopic renal surgery, in the hands of an experienced surgeon, appear to have comparable operative times. The advantages of laparoscopy for renal surgery in infants may be less than in other age groups given the typical rapid convalescence of this age group. Multiple studies have been conducted comparing intraoperative and postoperative outcomes between open and laparoscopic renal surgery. These comparative studies typically demonstrate increased operative times with a laparoscopic approach but a shorter hospital length of stay relative to the open cohort.

LRN for Wilms tumor has been reported, nearly always following neoadjuvant chemotherapy to downsize the primary tumor [46–49]. The pseudocapsule that is induced by chemotherapy may decrease the risk of tumor rupture and allow for safer manipulation of the tumor during LRN. In the largest series to date in 15 children, is that by Duarte *et al*. reported no intraoperative complications and sufficient lymph nodes were obtained to allow proper staging [49]. Using this minimally invasive approach, no local recurrences have been reported. Barber *et al.* described a series of LRN as the initial therapeutic modality in cases of suspected Wilms' tumor [47]. However, LRN for the treatment of Wilms' tumor has not yet established itself as the standard of care and has been performed only by experienced laparoscopic surgeons given the complexity of these cases.

Miscellaneous procedures

The application of laparoscopy to reconstructive surgical procedures of the kidney was inevitable after safety and efficacy was demonstrated for extirpative renal surgery. Laparoscopic pyeloplasty is covered in Chapter 86 and ureteroureterostomy is covered elsewhere in this textbook; however, there are many other renal procedures in which patients have appreciated the benefits of a laparoscopic approach.

Laparoscopic pyelolithotomy

The majority of surgically-treated stone disease in children is managed with established endourologic techniques, such as extracorporeal shock-wave lithotripsy, ureteroscopy or percutaneous nephrolithotomy (PCNL). However, laparoscopic pyelolithotomy has been described in pediatric patients who have failed established first-line stone therapies or those with large stone burden [50–54]. Pyelolithotomy has typically been performed concomitantly with correction of UPJ obstruction. Renal ectopia can make obtaining access for PCNL challenging and laparoscopic pyelolithotomy has been reported as an alternative in these unique circumstances [50].

A transperitoneal or retroperitoneal approach has been employed with removal of the stones accomplished *en bloc* with laparoscopic instruments when possible. Alternatively, if the stone cannot to be removed *en bloc*, it can be fragmented. The stone pieces can then be retrieved with a cystoscope and stone basket inserted into one of the trocars, with subsequent manipulation into the kidney through the pelviotomy. The use of an

Table 97.1 Outcomes of laparoscopic radical nephrectomy and nephroureterectomy.

Series	Year	Approach	Number of procedures	Patient age	Number of conversions	Mean operative time (min)	Complications	Length of stay	Comments
Koyle *et al.* [3]	1993	TP	1 RN	8 months	0	55	None	12 h	
El-Ghoneimi *et al.* [34]	1998	RP-Flank	31 RN	3 months -14 years	0	104	1 bacteremia	2 days	
Kobashi *et al.* [32]	1998	RP-Flank	20 RN	9 months -17 years	1	102	1 IVC laceration 3 peritoneal tears	Outpatient 2 days	
Borer *et al.* [21]	1999	RP-Prone	14 RN	3 months – 10 years	0	142	None	3 days	
Prabhakaran *et al.* [16]	1999	TP	4 RNU	1–5 years	0	176	None	2.6 days	
Hamilton *et al.* [24]	2000	TP	3 RN 4 RNU	4 months –12 years	0	175	None	23 h	Comparison between open surgery showing shorter length of stay but longer operative times
El-Ghoneimi *et al.* [33]	2000	RP-Flank	12 RN	7 months – 13 years	0	80-190	None	5 days	All patients had endstage renal failure requiring removal of native kidneys
Yao and Poppas [14]	2000	TP	14 RN 6 RNU	45 months	0	130	None	Outpatient 2 days	
Borzi [17	2001	RP flank + prone	21 RP prone 15 RP flank	5 years	0	Prone 47 Flank 65	4 peritoneal tears, all in RP flank	–	Partial ureterectomy was more distal with flank approach relative to prone
Kurokawa *et al.* [36]	2002	TP	4 RNU	5 years	0	195	1 subcutaneous emphysema	7 days	
Ku *et al.* [37]	2004	RP flank	10 RNU	1–13 years	0	150	None	2.5 days	Comparison between open surgery showing shorter length of stay and no difference in operative times

Continued

Table 97.1 *Continued*

Series	Year	Approach	Number of procedures	Patient age	Number of conversions	Mean operative time (min)	Complications	Length of stay	Comments
Borzi and Yeung [28]	2004	RP + TP	122 RN + RNU	3 months – 14 years	4	92	3 subcutaneous emphysema	1–8 days	
Steven *et al.* [38]	2005	TP	13 RN	10 months – 9 years	0	86	None	1 day	All RN performed for multicystic dysplastic kidneys
El-Ghoneimi *et al.* [39]	2006	RP + TP	100 RP flank 4 TP	20 days – 15 years	0	Unilateral 97 Bilateral 260	6 peritoneal tears	2–5 days	50% of RN in series were pretransplant nephrectomies
Garg *et al.* [40]	2006	RP prone	26 RN 4 RNU	3 months –10 years	0	58n	None	1 day	Single instrument port
Mahomed *et al.* [27]	2007	TP	122 RN + RNU	3 months –15 years	0	93	2 bleeding 1 acute renal failure	1 day	
Gundeti *et al.* [41]	2007	RP prone	38 RN	6 months – 17 years	1	160	1 peritoneal tear requiring open conversion	–	PD insitiued within 24 h in 15 of 19 children
Gundeti *et al.* [42]	2007	RP prone + TP	49 RP prone 51 TP	7 months – 14 years	2, one in each approach for bleeding	RP 96 TP 112	3 in RP 3 in TP	RP 1 day TP 2 days	Nonrandomized study showing no difference in postoperative analgesia requirements or complications.
Harper *et al.* [43]	2007	TP	3 RN 2 RNU	3–17 years	0	281	None	3 days	All for giant hydronephrosis
Fuchs *et al.*[44]	2009	TP	23 RN	3–7 mos	0	86	None	–	All patients younger than 1 year
Baez *et al.* [45]	2009	RP + TP	20 RP flank 10 TP	RP 66 months TP 88 months	2, one in each approach	RP 121 min TP 92 min	2 peritoneal tears	1–2 days	

TP, transperiteonal; RP, retroperitoneal; RN, radical nephrectomy; RNU, radical nephroureterectomy; IVC, inferior vena cava; PD, peritoneal dialysis.

internal or external drain is recommended following suture closure of the pelviotomy. Immediate stone-free rates have been reported to be 75–100% in this very challenging patient population, although in a very limited number of patients.

Laparoscopic calyceal diverticulectomy

Calyceal diverticula are infrequently encountered and can be complicated by stone formation or infection. Once again, endourologic techniques, such as ureteroscopy and percutaneous ablation, are the most commonly utilized procedures when treatment is necessary. Anterior calyceal diverticula are less amenable to access with the percutaneous surgical approach and an alternative surgical approach may be more appropriate given the patient's anatomy. To date reports of pediatric patients with laparoscopically treated calyceal diverticulum with or without robotic assistance have been published [55–57]. Indications for surgery were enlargement, pain, calculus or infection. Transperitoneal or retroperitoneal laparoscopic marsupialization and ablation of the diverticulum with electrocautery have been the techniques described. No complications or recurrences have been reported.

Laparoscopic renal denervation with nephropexy

Autosomal dominant polycystic kidney disease (ADPKD) will typically present in the adult population, but it can present in the pediatric age group. Pain is a common symptom and is hypothesized to be secondary to cyst enlargement resulting in compression of surrounding tissues, traction on the renal pedicle, and distention of the renal capsule. Casale *et al.* described a series of 12 patients, with mean age of 12 years, who underwent laparoscopic renal denervation for increasingly medically refractory flank pain [58]. The authors' technique involved splanchnic denervation via extensive dissection of the renal hilum and subsequent division of all perihilar nervous tissue. Full mobilization of the kidney and nephropexy with six 2-0 absorbable sutures completed the procedure. With average follow-up of 2 years, all treated patients were no longer taking analgesics and postoperative visual analog pain scores were significantly lower than preoperative scores.

Laparoendoscopic single-site surgery

The success of minimally invasive surgery in the form of laparoscopic surgery has inspired surgeons to improve the procedure. Decreasing the incisions from a traditional three ports to a single site has been the next evolution of laparoscopic renal surgery in children. The umbilicus is a naturally occurring scar and serves as the most utilized location for laparoendoscopic single-site (LESS) surgery. Potential benefits of LESS nephrectomy over traditional laparoscopic and open nephrectomy include improved cosmesis, reduction in iatrogenic visceral and vascular injuries from port placement, and possibly reduced cost from fewer ports. The first published report of transumbilical single-site LRN in a child was by Park *et al*. in 2009 [59]. In a 3-year-old girl a single ectopic ureter associated with dysplastic kidney was removed through a single incision in the umbilicus with a homemade single-port device. Subsequent LESS renal surgeries in children have been published with successful outcomes [60–62]. Innovations in current laparoscopic instrumentation will be necessary to make LESS an easier procedure to perform given the close proximity of working instruments at the single-port access site.

Extirpative surgery without skin incisions appears to be the ultimate in minimally invasive procedures in the abdomen. Natural orifice transluminal endoscopic surgery (NOTES) has been performed in a limited number of adult patients, either transvaginally or transgastrically [63]. Procedures have included cholecystectomy, appendectomy, and tubal ligation. NOTES transvaginal nephrectomy has been reported in an adult for atrophic kidney associated with recurrent UTIs [64]. While no NOTES urologic procedures have been reported in children, based upon history, we can only wait to see when this technique will be reported in a child. However, the enthusiasm to pursue a new surgical technique must be surpassed by the surgeon's ability to decide whether the new technique offers additional benefits over existing techniques and at no greater risk.

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CHAPTER 98

Minimally Invasive Techniques in Lower Urinary Tract Reconstruction

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Introduction

Minimally invasive surgery has an ever expanding role in urologic surgery. Particularly with the advent of robotic assistance, minimally invasive techniques have taken a major role in innovating and improving patient care. Although urologists have been among the first adapters of laparoscopy and robotics, pediatric urology to some extent has lagged behind this growth and innovation. However, in recent years, there has been a newly inspired growth and interest in adapting minimally invasive techniques in pediatric urology. We will discuss some of the most prominent of these surgical techniques and reported early results with them.

Vesicoureteral reflux surgery

Vesicoureteral reflux (VUR) represents the retrograde flow of urine from the bladder to the upper urinary tract during bladder emptying or filling. VUR can be primary, which is secondary to a congenitally incompetent ureterovesical junction (UVJ), or secondary, which is associated with other functional or organic dysfunction of the urinary tract leading to damage of the UVJ.

The goals of VUR treatment are to prevent pyelonephritis, renal injury, and other complications of reflux. The rationale of medical treatment of VUR is based on the historical finding of Ransley and Risdon in 1978, that sterile urine reflux does not cause renal scarring, and daily antibiotic prophylaxis has been the cornerstone in the initial management of children with reflux. Prophylaxis usually is continued until reflux resolves or until the risk of reflux to the individual is considered to be low. There are several medical therapy schemes available for VUR treatment; however, medical management of VUR needs a very close radiologic and laboratory follow up [1–3].

Since the first report by Puri *et al.* [4], endoscopic ureteral orifice bulking agent injection has become a more mainline treatment of reflux in children. The American Urological Association (AUA)_ in its present recommendation for reflux recognizes endoscopic injection of bulking agents as a mainline treatment [5]. The gold standard in the same document, however, remains open surgery to correct reflux, either intravesically or extravesically. Recently, surgeons have tried to simulate this success with open surgery in a minimally invasive fashion.

Robotic/laparoscopic extravesical reimplantation

Technique

The extravesical approach can be performed unilaterally or bilaterally, applying the Lich-Gregoir technique. The patient is placed in the supine position for an extravesical laparoscopic ureteral reimplantation. A ureteral catheter is placed to help laparoscopic identification and a Foley catheter to drain the bladder. Pneumoperitoneum is created via a Verres needle placed under the umbilicus or under direct vision, a first 5-mm trocar for vision

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is placed, and the other two trocars are placed along the lateral border of the rectus. The ureter is identified at the level of iliac vessels and the pelvic portion of the ureter is dissected free all the way to the detrusor by dividing the posterior peritoneum on the surface of the bladder. Adequate exposure of the posterior bladder wall is a key factor in this operation. A hitch stitch through the posterior bladder wall can be used to improve the exposure of the ureteral hiatus, attaching to the abdominal wall or through it. Once the ureter is free, the size of the tunnel is estimated after the bladder is partially distended. The ureter should course slightly laterally to avoid kinking of the ureter. A tunnel is adequately dissected to obtain a 5:1 ratio of length to width; the detrusor muscle is divided full thickness using a cautery hook while keeping the mucosa intact and the bladder is inflated at this point to make this dissection easier. Any perforations of the mucosa are closed using a 6-0 chromic suture. The ureter is positioned in the tunnel so as to avoid any kinking or excessive compression of the ureter to prevent obstruction. Closure may be from the proximal end of the incision to the distal end or in the reverse fashion. In the latter, the ureter is well visualized while in the former the needle needs to be passed under the ureter each time. The peritoneum is closed in a running fashion. Robotic extravesical reimplant mirrors the laparoscopic technique, but obviously provides better three-dimensional visualization and easier intracorporeal suturing.

A common problem is accidental bladder mucosal perforations during the dissection of the detrusor muscle trough for the sub-mucosal tunnel. The bladder mucosa perforations can be prevented by not over distending the bladder and use of blunt instruments like the suction tip to do the dissection of the mucosa from the detrusor muscle. Other limitations of this approach are transgressing the peritoneal cavity and difficulty in bladder retraction for want of better exposure.

Outcomes

Lakshmanan *et al*. reported extravesical laparoscopic reimplant in 99 ureters in 66 children aged 4–18 years [6]. With the first 13 cases (the initial learning curve) of their series excluded, they reported a success rate of 97.8% with a mean follow-up of 34 months. Shu *et al.* in 2004 took a similar approach and documented excellent results and recovery in postpubertal patients [7]. Lopez *et al*. reported their experience with 43 renal units with reflux in 30 children (17 unilateral and 13 bilateral) [8]. The mean operative time was 70 min for unilateral reflux and 124 min for bilateral reflux. At the same time as the procedure, one heminephrectomy and two ureteroceles were removed by laparoscopy and endoscopy, respectively. Urine leakage necessitated a redo reimplantation in one patient and one patient with bilateral VUR had voiding difficulty.

Casale *et al*. reported on 41 children undergoing bilateral robotic extravesical reimplantation for VUR [9]. Patients were 16–81 months old and the mean operating time was 2.33 h. On follow-up the overall success rate was 97.6%. It has been customary not to perform bilateral extravesical reimplantation of the ureters due to increased incidence of voiding dysfunction. However, it is important to note that none of these patients developed voiding dysfunction in spite of performing bilateral extravesical reimplant. The authors attribute this to the nerve-sparing approach that they used due to better visualization by the robot. Leissner *et al*., in their landmark article, described the relationship of the pelvic nerves to the ureter, and argued that the preservation of these nerves protects voiding function [10].

Transvescicoscopic reimplanatation

Technical aspects

The port placement is preceded by transurethral cystoscopy to allow placement of the first camera port under cystoscopic guidance. The bladder is first distended with saline and a 2-0 monofilament traction suture is passed percutaneously at the bladder dome under cystoscopic vision, through both the abdominal and bladder walls to keep the bladder wall from falling away. A 5-mm trocar is then inserted under cystoscopic vision. A urethral catheter is then inserted to drain the bladder and start CO_2 insufflation to 10–12 mmHg pressure. The urethral catheter is used to occlude the internal urethral meatus to secure CO_2 pneumovesicum and it can also serve as an additional suction irrigation device during subsequent dissection and ureteric reimplantation. A 5-mm 30° scope is used to provide intravesical vision. Two more 3–5-mm working ports are then inserted through the lateral wall of the distended bladder under vesicoscopic guidance

Ureteral catheters are inserted into the respective ureter as a stent to facilitate subsequent ureteral mobilization and dissection, and secured with suture. Intravesical mobilization of the ureter, dissection of the sub-mucosal tunnel, and a Cohen's type of ureteral reimplantation are then performed under endoscopic guidance, in a similar manner to the open procedure. Once adequate ureteral length is obtained, the muscular defect in the ureteral hiatus is repaired. A sub-mucosal tunnel is then created as in an open Cohen's procedure. A fine grasper is passed and the mobilized ureter is gently drawn through the tunnel. Ureteroneocystostomy is performed under endoscopic guidance with intracorporeal suturing. Persistent mild hematuria up to 72 h has also been observed, which settles spontaneously.

Outcomes

The first report on a minimally invasive approach for intravesical reimplant was published by Gill *et al.* in 2001 [11]. This initial report utilized a combination of vesicoscopic and endoscopic instruments with good results. Canon *et al.* compared open cross-trigonal ureteral reimplant with vesicoscopic reimplant [12]. Fifty-two children underwent vesicoscopic reimplant and 40 underwent open reimplantation of the ureter. Although the mean age (5.7 vs 4 years) was significantly higher in the vesicoscopic group and the mean reflux grade was significantly lower, outcomes were comparable in the two groups of patients, both with resolution rates more than 90%. The vesicoscopic group of patients had significantly less requirement for postoperative analgesia. Valla *et al*. reported a similar success rate for vesicoscopic cross-trigonal reimplantation of ureters for reflux [13]. Peters *et al*. adapted the robot to perform vesicoscopic cross-trigonal reimplantation of the ureters [14].

Ureteral reconstruction

Laparoscopic transureteoureterostomy

An indication for this procedure is inadequate length of the affected ureter due to proximal or mid-ureteral damage leading to the inability to perform either an ureteroneocystostomy with or without a psoas hitch or a Boari flap. The rationale for this procedure, first described in 1930 by Higgins, is to restore the continuity of the urinary tract and to spare a renal unit, without need for permanent external drainage (i.e. ureterocutaneostomy, pyelostomy) [15]. The only report of a pediatric series of laparoscopic transureteoureterostomy (TUU) was published in 2007 by Paggio and Gonzalez, in three patients [16].

Using three working ports, both the ureters are mobilized. The donor ureter is then divided and this ureter is passed underneath the sigmoid mesentery to be anastamosed to the recipient ureter on the other side. Laparoscopic TUU features magnification, allowing delicate movements during the procedure and helping in the performance of a precise anastomosis; one drawback of this procedure is the need for advanced laparoscopic skills and a lengthy operative time.

Robotic/laparoscopic megaureter tapering and reimplant

Minimally invasive techniques to reconstruct the megaureter have been published in the literature. Tailoring the ureter before reimplantation can be performed extracorporeally by dissecting the entire length of the ureter and dividing it at the distal end. The distal 5–7 cm of the ureter can then be delivered extracorporeally and tapered to the right size. It is then dropped back into the abdomen and reimplanted to the bladder in a nonrefluxing manner [17]. Agarwal *et al.* reported a technique utilizing a traction suture/vessel loop to provide a firm anchor to the ureter without dividing it from the bladder and thus aiding intracorporeal tapering [18]. These techniques can be easily adapted to the robot, as published by Hemal *et al.* [19].

Minimally invasive bladder and bowel continence procedures and bladder augmentation procedures

The role of bladder and bowel catheterizable channels to achieve continence and bladder augmentation for a poorly compliant bladder are well-established procedures in pediatric urology. The nature of these procedures demanded a significant sized open incision and hence these were ideal candidates for utilizing minimally invasive techniques like laparoscopy and robot-assisted laparoscopy. The first report using a minimally invasive procedure was by Jordan *et al*. [20]. They reported the laparoscopic creation of an appendicovesicostomy in a child with an obliterated bladder neck. Multiple reports have since been published on minimally invasive bladder reconstruction for augmentation and continence.

Procedures and outcomes

In spite of differences in technical details, most authors have chosen to use laparoscopy to mobilize the bladder and bowel, and to perform cystotomy and the final augment anastomosis to the native bladder. The bowel loop isolation, detubularization, and augment creation were performed extracorporeally. Hedican *et al*. in their series of eight patients in 1999, reported use of laparoscopy to perform a variety of procedures [21]. These included six patients who had bladder augmentation performed using extracorporeal reconstruction through a Pfannensteil incision or an existing midline scar. They felt that the scars were substantially smaller than when the entire reconstruction was performed in an open fashion. The same group later reported the early and long-term outcome with 7-year follow-up in 31 patients who had undergone laparoscopic reconstructive procedures [22]. Not all these patients were children (median age 14 years, range 1–36 years). In terms of operative and perioperative outcomes, there was one conversion to an open procedure secondary to dense adhesions. A variety of procedures were performed including appendiceal vesicostomy, Malone antegrade continence enema (MACE) channel creation, and bladder augmentation, with a total of 39 stomas and 16 bladder augments created in 29 patients. Early complications occurred in five patients and included bowel obstruction, deep vein thrombosis, and ileus. The median hospital stay in these patients was 6 days. On long-term follow-up, they found stoma revisions had been performed in 7.7% with a stomal stenosis rate of 5.5%, which is in line with the open experience.

In the largest series of laparoscopic bladder augmentation published to date, El-Feel *et al*. reported a mean operating time of 202 min and a mean hospital stay of 5 days [23]. Two patients had long-term complications unrelated to the surgical technique. They argued that the bowel anastomosis and the detubularization of the bowel is best performed extracorporeally, while others have reported that the entire procedure can be performed intracorporeally [24 –26].

To assess if there is really a benefit in performing laparoscopy in a patient who still requires an incision, albeit small, for the extracorporeal part of the procedure, Caddedu *et al.* compared open surgery with laparoscopy-assisted surgery [27]. In their study, the operative time and complication rate were comparable between the two groups. However, the time to return to regular diet and hospital stay were significantly shorter in the laparoscopy-assisted group when compared to patients who underwent open surgery. It is important to mention that neither of these groups included patients having bladder augmentation, and primarily consisted of patients undergoing MACE and Mitrafanoff procedures.

It would be a mistake not to mention the role of robot-assisted surgery in these days of rapid adaptation to new techniques. Totally laparoscopic augmentation of the bladder is tedious and time-consuming, mainly because of intracorporeal suturing. Robotic assistance makes this part easier to perform and hence might have a role to play in bladder augmentation procedures of the future. The first report using the robot to perform bladder augmentation in a child was published by Gundeti *et al*. from Chicago in 2008 [28], with excellent outcomes. Although this procedure lasted for 10 h, the authors should be commended for their effort. It can be hoped that with experience, the operating time will come down with retention of the benefits of minimally invasive surgery.

Minimally invasive approach for urachal remnants

Persistence of part of or the entire allantois can present in children with a patent urachus. By the fifth month of gestation, the urachus is nearly obliterated to ligamentous structure with an obliterated lumen lined by epithelium and an outer fibromuscular layer. This fibromuscular band then eventually becomes the median umbilical ligament. Depending on the part of the urachus that is persistent, patients may present with an urachal fistula, urachal umbilical sinus, vesicourachal diverticulum or urachal cyst (most common anomaly). Although these anomalies are seen in half of fetal specimens and persist in 2% of adults, they seldom become symptomatic [29]. If these anomalies do become symptomatic, they can present with infection or drainage. These symptoms are often persistent and recurrent and hence need surgical correction. It is well established that these lesions are at risk for developing adenocarcinoma later in life and this is another reason for surgical intervention. Surgical repair has traditionally been done in an open fashion, but laparoscopy can provide a minimally invasive approach to correct these anomalies.

Urachal remnants were first described and treated by Bartholomaeus Cabrolius in 1550 and since there have been multiple reports on their open surgical management [30]. Tronsden *et al.* in 1993 described the first laparoscopic approach to the excision of urachal remnant [31]. Since then multiple case series have been reported and show this technique to be a feasible and safe option for the surgical management of urachal remnants, even in children [32–36].

Surgical technique

Initial reports were of this technique performed in adult patients, and later in children. Although the surgical principles are the same in most of these reports, the optimal port placement has undergone a transition to laterally placed ports from cranially placed ports, particularly in children, to provide a better view of the urachal remnant. In the largest series of laparoscopic treatment of urachal remnants in 27 children, Turial *et al.* considered that the lateral approach provided a better visualization of the operative field [36]. A 5-mm laparoscope (alternatively a 1.9-mm scope) is placed in the left lateral aspect of the umbilicus, lateral to the rectus muscle. Two more ports are placed on either side of this camera port. The left medial umbilical ligament has to be divided to provide a clear view of the urachal cyst. The umbilical end of the urachal remnant is cauterized and divided. The bladder end is taken with or without bladder cuff as appropriate and the bladder sutured closed as needed. A Foley catheter in the bladder makes it possible to easily delineate the bladder and check closure after repair. Alternatively, the laparoscope can be placed either cranial to the umbilicus in the midline or in the lateral edge of the rectus fascia. The potential disadvantages of this are the proximity of the camera to the urachal lesion.

The laparoscopic approach has been universally found to be a safe and reliable technique to surgically correct urachal remnants. In adults, adenocarcinoma arising in urachal remnants has been successfully treated with laparoscopy. In the largest series in children by Turial *et al*., median operative time was 35 min with no complications [36]. Postoperatively, the children did not have any complications with a median follow-up of 7 months. It has been utilized as a one-stage approach even for infected urachal cysts with excellent results [36]. According to these authors who used a 2–5-mm camera and 2-mm instruments, laparoscopy provided a superior cosmetic outcome and early recovery. Other authors have also concluded, although not from comparative studies, that laparoscopy provides earlier recovery and better cosmetic outcomes [34].

Minimally invasive genitoplasty

Children born with congenital absence or hypoplasia of the vagina in isolation (Mayer–Rokitansky–Kuster–Hauser syndrome) or in association with other anomalies, like disorders of sexual development or genitourinary development, should be considered for vaginoplasty. A good preoperative work-up is necessary to accurately diagnose this condition and define appropriate treatment. Most experts in this field agree that gradual vaginal dilation should be the first step in the management of these children [37]. If this is unsuccessful, then surgical reconstruction is considered. The timing of reconstruction is controversial and the recent impetus has been to perform these procedures during adolescent or early adult life due to better psychologic acceptance by these age groups [37].

Several different techniques of open vaginoplasty have been described in the literature, including the Vecchietti procedure, Davydov procedure, and intestinal vaginoplasty. All these techniques have recently been adapted to laparoscopic technique with good results, although the experience is still early. Although a detailed explanation of the various surgical techniques is beyond the scope of this chapter, we will attempt to provide an outline, as well as evidence for the feasibility of the minimally invasive approach.

Laparoscopic Vecchietti procedure

The principle of the Vecchietti procedure is traction from inside rather than dilation. The procedure involves placement of an acrylic ball in the superficial surface of the vaginal dimple. This is connected by wires under tension that pass through the vaginal dimple into the abdominal cavity and out through the anterior abdominal wall to a tightening device. The wires are placed under laparoscopic guidance and passed through the vaginal dimple and attached to the acrylic ball. Traction is applied to the vaginal dimple by gradually tightening these wires and elongating and enlarging the vaginal vault. Laparoscopy was utilized as early as 1992 by Gauwerky *et al.* [38]. A retrospective comparative study by Borruto *et al.* found that laparoscopy was equivalent to traditional approaches in terms of outcomes (neovaginal length 74.9 mm vs 73.7 mm) and complications (0% vs 13%) [39]. Fedele *et al.* reported excellent long-term functional results in 110 patients who underwent the laparoscopic Vecchietti procedure [40].

Laparoscopic Davydov technique

The Davydov technique involves the creation of a neovaginal space and then the use of the patient's own peritoneal lining to cover the space. The large bowel serosa is tacked on the abdominal side to the peritoneum anteriorly to close the neovaginal space from the abdominal cavity. The neovaginal space can be created by making a U-shaped perineal flap and bluntly dissecting between the bladder and the rectum. Laparoscopy has been utilized to mobilize the peritoneum and capping the neovagina with bowel serosa. Fedele *et al.* published their experience with the laparoscopy-assisted Davydov procedure in 30 patients, the largest series to date [41]. They found an excellent 95% anatomic success rate and 96% functional success rate at 6 months. Although their follow-up is short and this is still early experience, these are very promising results.

Intestinal vaginoplasty

Intestinal vaginoplasty involves harvesting a segment of bowel and using this segment to create a neovagina. Surgeons have used ileum or colon for this procedure [37, 42, 43]. Recently, the da Vinci robotic system was used to perform this procedure in a 17-year-old patient [44]. Laparoscopy was utilized for bowel mobilization, segmental resection, and re-establishment of bowel continuity. Two large series from China, one using ileum [42] and the other using colon [43], have both reported excellent safety and feasibility, with excellent postoperative functional outcomes.

Conclusions

Laparoscopy is an excellent minimally invasive option to surgically correct urachal remnants in children. This technique can be utilized even in children with an infected urachal cyst. It is a safe and reliable technique with possible but not proven better recovery and cosmetic appearance compared to open surgical repairs.

Laparoscopy is in its infancy with regards to reconstructive bladder and lower urinary tract surgery, particularly in children. Most reported experiences have been for older children or young adults. We hope that more experience and concomitant technologic innovations will push the frontiers in minimally invasive surgery and bring its benefits to children needing urologic reconstruction.

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CHAPTER 99

Laparoscopic Management of the Undescended Testicle

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Introduction

Prior to the advent of laparoscopy, the gold standard for localizing and managing the nonpalpable testis was open surgical exploration. This surgery began with an inguinal incision that was extended so as to access the retroperitoneum if a testis, nubbin or blind-ending vessels was not identified. In cases of bilateral nonpalpable testes, a Pfannenstiel incision was not uncommon. If a testis was identified, an orchidopexy or orchiectomy was performed depending on its perceived viability. While the success rate of this approach was acceptable, the approach began to change in 1976 when Cortesi *et al.* described the laparoscopic identification of an intra-abdominal testis [1]. Subsequently, there was confirmation of the safety and utility of diagnostic laparoscopy. The next evolutionary step came with the reports of therapeutic laparoscopy (orchidopexy and orchiectomy) by Bloom [2], Jordan *et al.* [3], and Bogaert *et al.* [4]. Today, laparoscopy has largely replaced open surgery for evaluating and managing the nonpalpable testis. The benefits of the laparoscopic approach over the open approach are seated in its superior accuracy for localizing the testis and its minimally invasive nature to achieve superior surgical results for testis viability and position.

Epidemiology

Cryptorchidism is a common congenital anomaly present in about 3% of full-term newborn boys [5–8]. The testis may be present in the abdomen or be palpable anywhere along the normal path of descent. Cryptorchidism is more commonly unilateral than bilateral (1.6–1.9%) and is more common among the premature (30.3%), suggesting that testicular descent may not be complete until near term [5]. Low birth weight is a particular risk factor for cryptorchidism, which affects 7.7%, 2.5%, and 1.4% of boys weighing under 2000 g, 2000–2499 g, and over 2500 g at 3 months [6]. The simultaneous presence of hypospadias and cryptorchidism occurs more commonly than would be predicted [9], and a diagnosis of a disorder of sexual differentiation needs to be entertained. There is a familial predisposition to cryptorchidism as the risk to a newborn male is 6.9-fold if he has an affected brother and 4.6-fold if he has an affected father [10, 11].

Testes may continue to descend postnatally into the scrotum [7, 11]. Wenzler *et al.* found that 70–77% of cryptorchid testes descended spontaneously, usually by 3 months of age, and only 6.9% of testes descended after 6 months of age [12]. While the exact cause of cryptorchidism is unknown, birth weight alone appears to be a principal determinant independent of the length of gestation [13–15]. The incidence of cryptorchidism is 1% by age 1 year and remains constant throughout adulthood.

Classification and implications

The simplest way to classify cryptorchidism is to stratify the position of the cryptorchid testis based on physical

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examination as either palpable (distal to the internal inguinal ring) or nonpalpable (intra-abdominal) [16]. Approximately 80% of cryptorchid testes are palpable and 20% are nonpalpable. Among the latter group, about 50% of boys will have an intra-abdominal testis. The intra-abdominal testis is usually located a few centimeters proximal to the internal inguinal ring, although it may be present anywhere between the ring and the lower pole of the kidney. The "peeping" testis lies at the entrance of the internal inguinal ring and can move between the abdominal cavity and inguinal canal. The nonpalpable testis is intra-abdominal (as described above), absent (vanishing) or atrophic. The absent (vanishing) testis is diagnosed at exploration when blind-ending spermatic vessels are encountered proximal to the internal inguinal ring. Atrophic testes are smaller than normal and may be found anywhere along the course of normal descent: intra-abdominal to scrotum.

Cryptorchidism predisposes men to subfertility and testicular cancer. Unilateral cryptorchidism may impair fertility in 50–70% of boys and 75% of those born with bilateral cryptorchidism despite orchidopexy [17]. Despite greater histologic deterioration with higher testicular position, and accordingly worse fertility, paternity may be similar in both abdominal and extra-abdominal unilateral undescended testes [18]. Instead, reduced serum levels of inhibin B (reflective of Sertoli cell function and seminiferous tubule integrity) may better predict impaired spermatogenesis [19]. Men with a history of cryptorchidism are about 10 times more likely to develop testicular cancer over the general population. While orchidopexy may not reduce the risk of testicular cancer, the scrotal position allows for easier examination and perhaps earlier detection [20]. Moreover, it may improve fertility or diminish the potential for malignant transformation.

Evaluation of the nonpalpable testis

History

The evaluation of the child with cryptorchidism starts with a thorough history, which should include questions regarding the pregnancy (including the use of steroids), initial physical findings at birth, change in position or palpability of the testes, medical and previous surgical history, and also a family history of cryptorchidism or syndromes.

Physical examination

The best physical examination for the testes requires a cooperative and relaxed child. The examination starts with the child in the supine position but other positions, such as frog-legged or squatting, may be more useful at times to relax the cremaster muscle of the spermatic cord. Notation should be made of any penile abnormalities (hypospadias, ambiguous genitalia), scrotal symmetry or underdevelopment, and the inguinal canal for a bulge consistent with the presence of the testis. The room and examiner's hands should be warm, and the child should be made aware of the impending palpation. The fingers are swept from the area above the internal ring down along the inguinal canal and then into the scrotum. The testis might be palpable under the fingertips or it may snap back into the abdomen. Soapy water may facilitate the examination by reducing friction between the child's skin and the examiner's fingers. The size of the solitary palpable testis has been offered as a harbinger of monorchidism by several authors who found that a contralateral testis length of greater than 2.0 cm represented compensatory hypertrophy [21–23]. The limitation of performing a physical examination in a child is highlighted by Cisek *et al.* [24], who found 18% of "nonpalpable" testes to be palpable during physical examination under anesthesia and that 12.6% of viable testes were distal to the inguinal canal.

Imaging

It is not possible to advocate for routine use of any imaging modality to localize a nonpalpable testis without confirmation by some means of exploration [25–29]. Ultrasound is commonly ordered to localize the nonpalpable testis; however, it rarely localizes a true nonpalpable testis and only identifies 18% of intracanalicular testes [30]. Magnetic resonance imaging (MRI) and gadolinium-enhanced magnetic resonance angiography carry higher sensitivity [31], but are less accurate than laparoscopy, expensive, and require anesthesia. In select cases, imaging may be helpful for patients at significantly increased risk of general anesthesia. In addition, should imaging identify a structure deemed to be a testis, surgical exploration is indicated for confirmation of its presence, as well as to determine whether the testis is viable or dysmorphic/hypoplastic and to identify nonunion abnormalities, neither of which can be properly determined radiologically

Hormonal therapy

Various protocols have been offered using gonadotropin-releasing hormone (GnRH), human chorionic gonadotropin (hCG)-β or testosterone to stimulate testicular descent. The basis for this approach stems from experimental observations that testicular descent is androgen mediated [32]. hCG directly stimulates Leydig cells to produce testosterone, while GnRH stimulates luteinizing hormone (LH) release by the pituitary, which promotes testosterone production. Successful descent is more common in older boys and in retractile testes or those distal to the external inguinal ring [33, 34]. Hormonal therapy is rarely therapeutic in cases of nonpalpable testes; however, occasionally the testis may descend to a palpable position which changes the surgical approach. Occasionally, nonpalpable testes can fully descend [35]. This option is best applied to boys with bilateral nonpalpable testes.

Surgical management

Timing

The current recommended timing for orchidopexy is between 6 and 12 months of age. This recommendation is based on several considerations including: (1) histologic evidence of impaired germ cells after 18 months of life [36, 37]; (2) spontaneous testicular descent may occur in the first 6 months; (3) testicular growth is more common in children operated on before age 18 months compared with those operated on at an older age [38]; (4) early orchidopexy enhances adult Leydig cell function [39]; and (5) anesthesia risks decline after age 3 months.

Diagnostic laparoscopy

There are significant implications of leaving an intra-abdominal testis in place, particularly with respect to a delayed diagnosis of malignancy. Therefore, the primary goal in these children is to identify the presence or absence of a viable testis. Radiologic imaging is insufficiently sensitive to localize the gonad and incapable of assessing viability. In contradistinction, diagnostic laparoscopy is safe [40], carries an accuracy rate greater than 95% [41, 42], and can identify testes that have previously been deemed absent by open exploration [43, 44].

Surgical technique

The child is placed supine after administration of general anesthesia. The surgeon may choose to frog leg the lower extremities to facilitate access to the scrotum and to tuck the arms rather than to extend them on boards that may interfere with positioning of the surgeon's body during laparoscopy. The patient should be prepared and draped from above the umbilicus to the mid thighs and laterally to the side walls. The monitor should be placed at the foot of the table.

Diagnostic laparoscopy begins by either blind passage with a Veress needle or direct open access to the abdominal cavity. The abdominal skin is grasped to elevate the umbilicus and the Veress needle passed by puncturing the umbilicus. Entry into the abdominal cavity can be tested by ascertaining negative aspiration with a syringe, a positive drop test, and very low intra-abdominal pressure measurements. Subsequent to creation of pneumoperitoneum, a skin incision is made in the region of the umbilicus (vertical through the umbilicus or semilunar, either supraumbilical or infraumbilical) and the trocar is pushed or twisted (according to the nature of the bladed trocar) until the abdomen is entered. What has been described is a two-step procedure, with both steps requiring blind passage of instruments into the abdomen. Our preferred method for access to the abdominal cavity is the open technique which reduces the risk of injuring the intra-abdominal contents, particularly given the small distance between the abdomen and back in such small children. This approach begins with one of the skin incisions listed above and dissection down to the rectus fascia. A horizontal mattress suture of 3-0 polyglactin is placed into the fascia at this point, which facilitates closure. The rectus fascia is then opened in the middle of the horizontal mattress suture and the properitoneal fat spread to expose the peritoneum. The peritoneum is grasped with atraumatic forceps and then with two small mosquito clamps after ensuring that bowel has not been grasped. The peritoneum is them opened sharply and a 5-mm trocar inserted into the abdomen (Figure 99.1). Insufflation of the abdomen is accomplished using carbon dioxide at flow rates of 8–10 L/min to achieve a pressure of 8–10 mmHg. There are several adjunctive maneuvers to improve visibility in the pelvis: aversion of nitrous oxide by the anesthesiologist which may distend the small bowel; placement of a rectal catheter to reduce air in the rectum; placement of a urethral catheter to empty the bladder; and placing the table in Trendelenburg position to draw the bowel cranially.

Inspection of the pelvis is best performed with a 30° lens. The bladder should be positioned in the center of the operative field between the paired median umbilical ligaments and the urachal remnant noted at the dome running cranially toward the umbilicus. The presumed normal contralateral side should be inspected first as a basis for comparison of the affected side. The vas deferens is seen coursing from the pelvis on either side of the midline, crossing over the median umbilical ligaments towards the corresponding internal ring. The internal inguinal ring is identified from the convergence of the spermatic vessels with the vas deferens on the nonaffected side. There should be inspection for an open contralateral internal inguinal ring and if noted, this can be corrected laparoscopically at the same setting [45]. Caudal traction on the descended testis can help visualize the cord structures. Inspection of the internal ring on the affected side will show one of the following scenarios (Figure 99.2):

- An intra-abdominal testis attached to normal vessels and vas with an open or closed ring. The processus

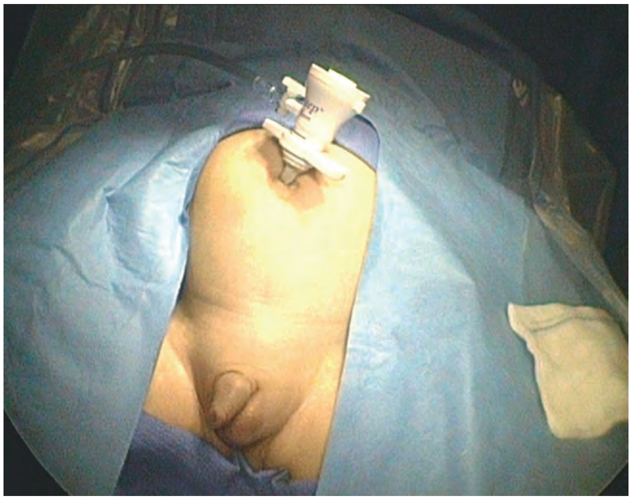

Figure 99.1 Example of a 5-mm port placed in the umbilicus through a vertical incision. This port is used for the 30° lens laparoscope for either diagnostic or therapeutic laparoscopy.

vaginalis may be patent and a long-looping vas deferens may descend through the open ring into the inguinal canal. In many cases of an open inguinal ring with normal appearing vessels and vas deferens, the testis will be seen within 1 cm of the ring. The internal inguinal ring may be closed and the testis located more proximally along the course of descent in the area of the kidney or may cross-over ectopically. Thus, the entire abdomen should be inspected if the testis is not apparent. If the left colon or cecum is hiding the testis, additional ports may be needed for proper dissection and confirmation of the presence or absence of the testis.

- Cord structures entering the internal ring that may indicate gonadal tissue distal to the ring. If the testis is peeping into an open ring, it can be pushed into the abdomen by massaging the canal. If spermatic vessels and vasa pass through the internal ring, a search for viable testicular tissue should be undertaken. Although atretic vessels are associated with nonviable testicular tissue, De Luna *et al.* found residual tubules in approximately 10% of remnants, of which 5.6% contained germ cells [46].
- Vessels ending blindly proximal to a closed internal ring without attached testicular tissue. A vanishing testis due to vascular compromise can only be confirmed by finding blind-ending vessels and not just an atretic vas deferens, although the latter is commonly associated with blind-ending vessels. Approximately 36–64% of children with a nonpalpable testis will be monorchid [24, 42, 47–50].
- A blind-ending vas seen without testicular vessels in the vicinity of gonadal disjunction. The laparoscopic exploration should continue cranially toward the origin of the testicular vessels until the gonad is located.

Diagnostic laparoscopy will determine whether a testis or testes are present in the abdomen. In nearly 50% of cases, no testis will be found; the vanishing testis syndrome [24, 51]. The surgeon must determine the viability of the gonad(s) and whether orchidopexy or orchiectomy is indicated. If orchidopexy is to be performed, then the need for a Fowler–Stephens procedure must be determined (ideally before surgical intervention is initiated). Another potential finding is the presence of a gonad distal to the internal inguinal ring that was not found on physical examination and requires further exploration and management. Once diagnostic laparoscopy has established the clinical landscape, the decision to transition to therapeutic laparoscopy or open surgery can be made based on surgeon experience and comfort.

Diagnostic laparoscopy poses few complications. Subcutaneous emphysema and hematoma are minor problems that seldom cause abortion of the procedure. The potential for major complications such as injury to vessels and intra-abdominal organs is rare using an open technique for access. The risks during therapeutic laparoscopy are similar to those for diagnostic laparoscopy, except for greater potential to injure adjacent organs and structures. Hsieh *et al.* reported three bladder injuries among 101 laparoscopic orchidopexies [52]. They recommended establishing the border of the bladder by modulating the volume of fluid in the bladder via a urethral catheter; careful perivesical dissection, particularly in boys with prior inguinal surgery; and maintaining a high index of suspicion, particularly in the presence of hematuria.

Laparoscopic orchidopexy

Laparoscopic orchidopexy was first described in 1992 by Jordan *et al.* [3], who then described the laparoscopic staged Fowler–Stephens procedure in 1994 [53]. Since then, several thousand cases have been described, reporting excellent success rates, often superior to reported open surgical cases. Docimo conducted a meta-analysis of open surgical orchidopexy and found an overall success rate of 76.1%: transabdominal orchidopexy 81%; single-stage Fowler–Stephens orchidopexy 67%; and two-stage Fowler–Stephens orchidopexy 73% [54]. In comparison, Baker *et al.* reported on a multi-institutional compilation of laparoscopic orchidopexy cases and found a 97.2% success rate for non-Fowler–Stephens orchidopexy, 74.1% for one-stage Fowler–Stephens orchidopexy, and 87.9% for two-stage Fowler–Stephens orchidopexy [55]. The atrophy rate was 6.1% for all cases and only 2% for the non-Fowler–Stephens cases. The single-stage Fowler–Stephens orchidopexy carried a higher atrophy rate (22%) that the two-stage procedure (10%). Comparing these two

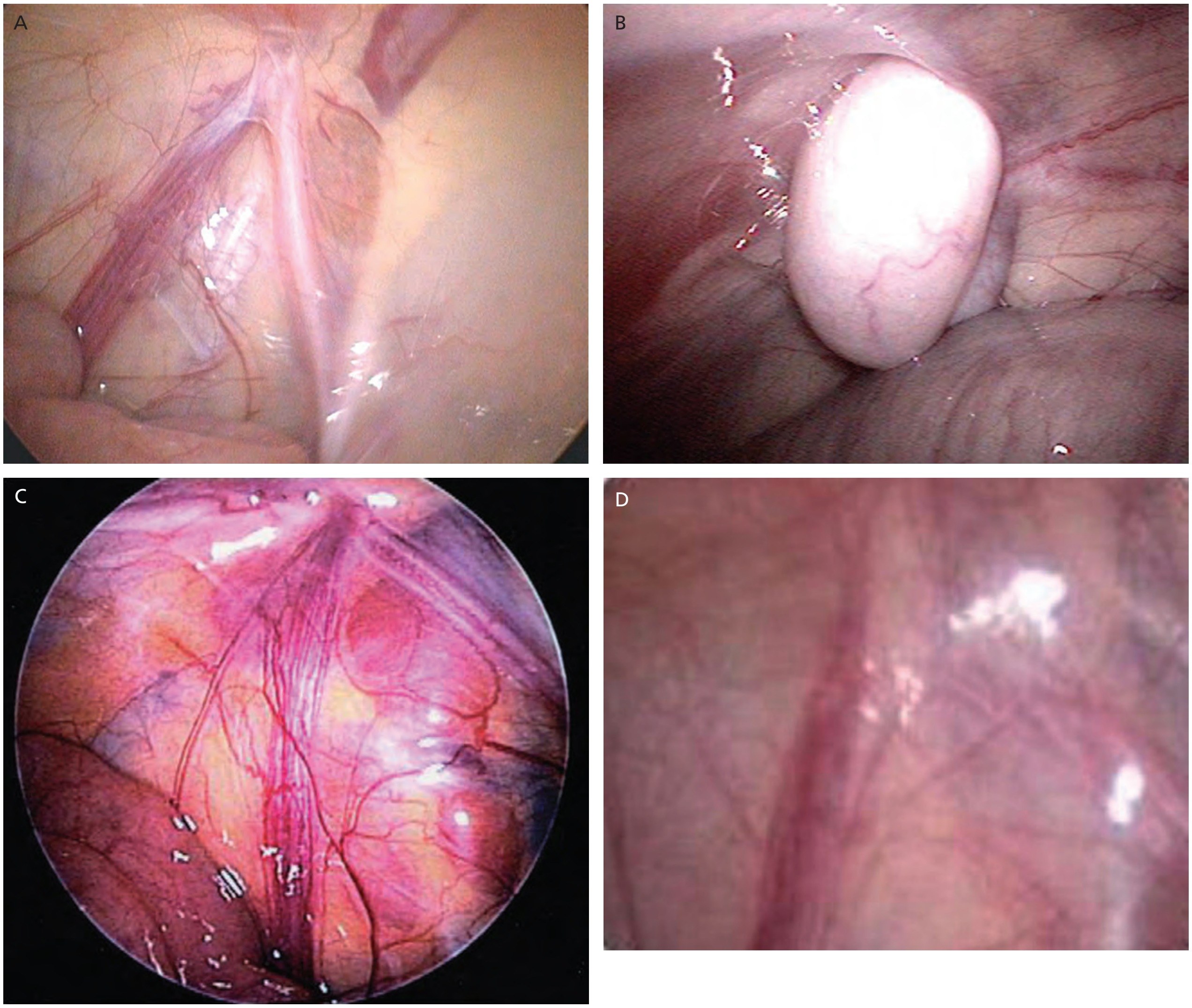

Figure 99.2 Laparoscopic views of the pelvis in the area of the internal inguinal ring. (A) Normal closed internal inguinal ring with healthy vessels and vas deferens. (B) Intra-abdominal testis subtended by normal internal spermatic vessels and vas deferens. (C) Vas and atretic vessels entering into a closed internal inguinal ring. Scrotal exploration identified an atrophic nubbin with visible hemosiderin. (D) Blind-ending spermatic vessels and vas deferens consistent with vanishing testis syndrome.

studies, laparoscopic orchidopexy yielded superior results to open orchidopexy regardless of the specific technique used. Unfortunately, long-term data are sparse but Esposito *et al.* reported on 12 patients with at least 10-year follow-up who underwent a two-stage laparoscopic Fowler–Stephens procedure [56]. The operated on testis was always smaller than the normal testis, despite good vascularization on Doppler ultrasound in 10 testes (83.3%); two (16.7%) testes were atrophic.

The success of this procedure is predicated on the final position of the testis in the scrotum and its viability. A satisfactory position is generally considered to be dependent in the scrotum which facilitates later physical examination. Viability reporting generally reflects the subjective opinion of its author. Causes of atrophy include maintenance of the testis on tension after fixation, skeletonization of the vessels, significant vasal dissection, and delayed ligation of the internal spermatic vessels because of inadequate length. Lindgren *et al.* reported an overall 93% success rate and no cases of testicular atrophy when either primary or Fowler–Stephens laparoscopic techniques were used [57]. Chang *et al.* reported that prior surgery was a risk factor, again due to loss of collateral vessels [58]. In that same report, they reported an overall 85% success rate for all Fowler–Stephens procedures and a 4% atrophy rate. In a more recent report from the same group, Samadi *et al.* noted a 95% success rate among 203 laparoscopic orchidopexies, and considered that this high success rate could be attributed to minimal manipulation of the testicle during dissection, a wider peritoneal window, and sparse use of electrocautery [59]. Dave *et al.* compared testis viability by Doppler after initial laparoscopic testicular vessel ligation followed by a second-stage Fowler–Stephens orchidopexy performed laparoscopically (61 testes) or open (12 testes) [60]. The atrophy rate was 20.5% in the laparoscopic group and 0% in the open group. None of the five testes with long-looping vas atrophied following open orchidopexy, while five of six (83%) atrophied after laparoscopic orchidopexy (*P* = .03). They concluded that perhaps the second-stage procedure should be performed in an open fashion to better preserve collateral vessels.

Surgical techniques (see Video 99.1)

The positioning of the child, preparation and draping, placement of adjunctive catheters, and anesthetic considerations are the same as those described above for diagnostic laparoscopy. Since therapeutic laparoscopy starts with a diagnostic evaluation, the placement of the umbilical port, insufflation considerations, and inspection are the same. The surgeon should stand on the contralateral side of the affected testis. The monitor is best positioned at the foot of the table. Once it is determined that a viable testis is present in the abdomen and that laparoscopic orchidopexy will proceed, two additional ports (3 or 5 mm) are placed. Radially dilating 5-mm ports allows the use of smaller incisions without compromising the use of small instruments, including a 5-mm clip applier if needed. The skin incision should accommodate the size of the ports and the subcutaneous tissue spread before placement of the ports. These ports should be placed under direct vision through the laparoscope in the umbilical port so as to avert injury to any intra-abdominal structures. The two working ports can be placed at the level of the umbilicus and the mid-clavicular line (Figure 99.3) or alternatively, a port ipsilateral to the intra-abdominal testis is placed below the subcostal margin and the second port is placed in the contralateral lower abdominal quadrant.

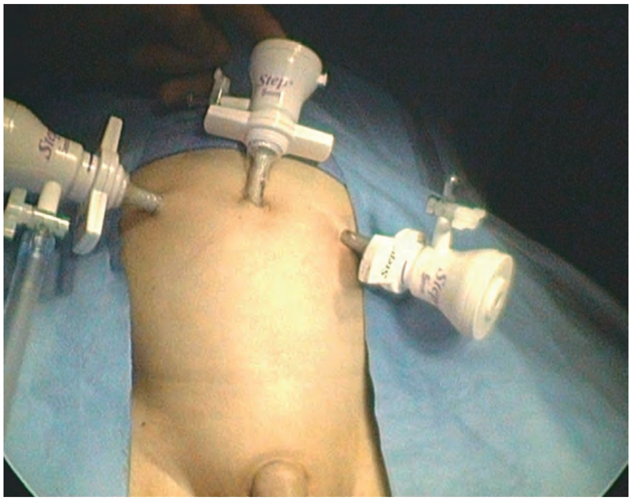

Figure 99.3 Port placement for laparoscopic orchidopexy in a child with an intra-abdominal testis. The two 5-mm ports are placed at the level of the umbilicus and the mid-clavicular line.

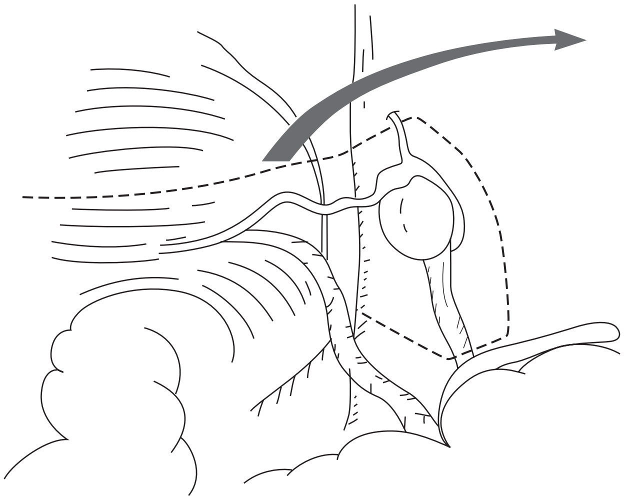

Figure 99.4 Lines of incision for the laparoscopic orchidopexy: lateral to the internal spermatic vessels, caudad to the vas deferens, and around the internal ring (reproduced from Chang, M., Franco, I. Laparoscopic Fowler–Stephens orchiopexy: the Westchester Medical Center experience. *J Endourol* 2008;22:1315–1319, with permission of Mary Anne Liebert).

Non-Fowler–Stephens orchidopexy

The peritoneal dissection can be divided into three parts that become continuous upon completion (Figure 99.4). The first peritoneotomy is made sharply lateral to the testicular vessels, and carried inferiorly to the inguinal ring and then superiorly as high as can be easily accessed, and when necessary, more proximally toward the origin of the vessels. The next incision is caudad and parallel to the vas deferens from the internal ring, and carried across the obliterated umbilical ligaments toward the bladder. Care should be taken to avoid deep dissection and inadvertent injury to the bladder or vessels of the umbilical ligament. Monopolar electrocautery should be used sparingly and at low current settings to avoid direct or collateral damage to vital structures. The peritoneotomies at the level of the inguinal ring should be connected. The third dissection involves drawing in the peritoneum that enters the internal ring (patent processus vaginalis), with care taken to avoid grasping a looping vas deferens. The gubernaculum is transected using electrocautery or perhaps a LigaSure (Valleylab, Boulder, CO, USA) or Harmonic scalpel (Ethicon Endo-Surgery Inc, Cincinnati, OH, USA). This dissection leaves a triangle of peritoneum between the spermatic vessels and the vas deferens with the testis positioned at the apex.

Using the gubernacular attachment as a handle, the triangle of tissue (vessels, testis, and vas) is elevated cranially, taking care not to harm the external iliac vessels, inferior epigastric vessels or long-looping vas. A dissecting Kuttner or the backside of laparoscopic scissors can be used to tease the tissue off the vessels. To determine if there has been adequate dissection, the testis can be retracted towards the contralateral internal ring; in most cases, if the testis reaches beyond this point without traction, there is sufficient length to place it dependently in the scrotum. Any remaining attachments that retard the mobility of this pedicle should be released. If the extent of the dissection fails to provide sufficient length, additional dissection of the spermatic vessels should be performed toward their origin. Should additional length be needed, a relaxing incision of the triangle of peritoneum can be carefully made from the vessels to the vas deferens, which may significantly lengthen the vessels. Before making this incision, however, the surgeon must assess whether this maneuver will provide the required length; if not, it would be appropriate to consider a Fowler–Stephens procedure and divide the internal spermatic vessels and preserve the collateral vessels associated with the peritoneum. Ideally, the vessels should be transected before any of the above described incisions are made (see below).

The next step in the operation involves creating a neohiatus and delivery of the testis into the scrotum (Figure 99.5). In order to shorten the distance into the scrotum, a peritoneotomy is made lateral to the bladder and medial to the umbilical ligament, and this space is developed. A dissecting instrument is passed over the pubis and into the scrotum. A subdartos pouch is then created over the point of the dissector, which then is passed through the scrotal fat. Removing some of this fat can facilitate the next step, which is to pass a 5- or 10-mm trocar with a beveled end retrograde over the dissector and into the abdomen under direct vision. This trocar is easiest to pass if it is rotated through 360° while pushing, which negotiates it away from any intervening tissue. A locking grasper is then passed through the scrotal trocar to grasp the gubernacular stump. Once the proper orientation of the testis and cord is ascertained, the testis is drawn to the trocar and both are brought out to the scrotum. The gubernaculum is secured with a mosquito clamp and inspection is made to confirm proper orientation and laxity of the pedicle. Additional dissection is performed to gain length if the testis is not dependent in the scrotum. Once a tension-free dependent testis can be positioned in the scrotum, it is fixed in the pouch according to the surgeon's usual technique (Figure 99.6). Hemostasis of the operative field is evaluated under low intra-abdominal pressure. It is not necessary to close the ipsilateral internal ring as the area scars and clinical hernias do not appear to develop. The lateral ports are removed sequentially, the fascia closed with absorbable suture under direct vision, and the abdomen insufflated. Hemostasis should be assessed at the port sites. The abdomen is desufflated through the umbilical port and then closed with the horizontal mattress suture placed earlier in the operation. Before securing this stitch, it is important to ensure that the port sites are free of bowel and omentum. The port sites are closed subcuticularly and then dressed. Analgesia can be achieved by either caudal anesthesia or local injection of bupivacaine hydrochloride.

Single-stage Fowler–Stephens laparoscopic orchidopexy

As mentioned above, there are cases when the vessel length is found to be insufficient to allow the testis to reach the desired scrotal position. A single-stage Fowler–Stephens procedure can be performed where the testicular artery and vein are clipped and transected [alternatively, the vessels can be divided using a LigaSure (Valleylab) or Harmonic scalpel (Ethicon Endo-Surgery Inc], preserving the vasal blood supply to the testis (Figure 99.7). This frees the testis so that it can be placed in the scrotum. However, division of the testicular vessels is associated with higher atrophy rates.

Two-stage Fowler–Stephens laparoscopic orchidopexy

If diagnostic laparoscopy reveals a high testis that cannot reach the scrotum without transection of the testicular vessels, a two-stage Fowler–Stephens laparoscopic orchidopexy can be used. In the first-stage, a peritoneotomy is performed over the internal spermatic vessels proximal to the iliac vessels. The vessels are ligated using 5-mm vascular clips and then divided. Six months later, the testis is brought to the scrotum laparoscopically, based on the enhanced contribution of the paravasal vascular supply. The principles for the technique for the second stage of the procedure are as described for the non-Fowler–Stephens procedure above: peritoneal incisions are made lateral to the divided vessels and distal to the vas deferens; the triangle of peritoneum is developed, taking care to preserve all of the collateral vessels; the gubernaculums is divided; the pedicle is dissected off the posterior abdominal wall; and the testis brought into the scrotum through a neohiatus.

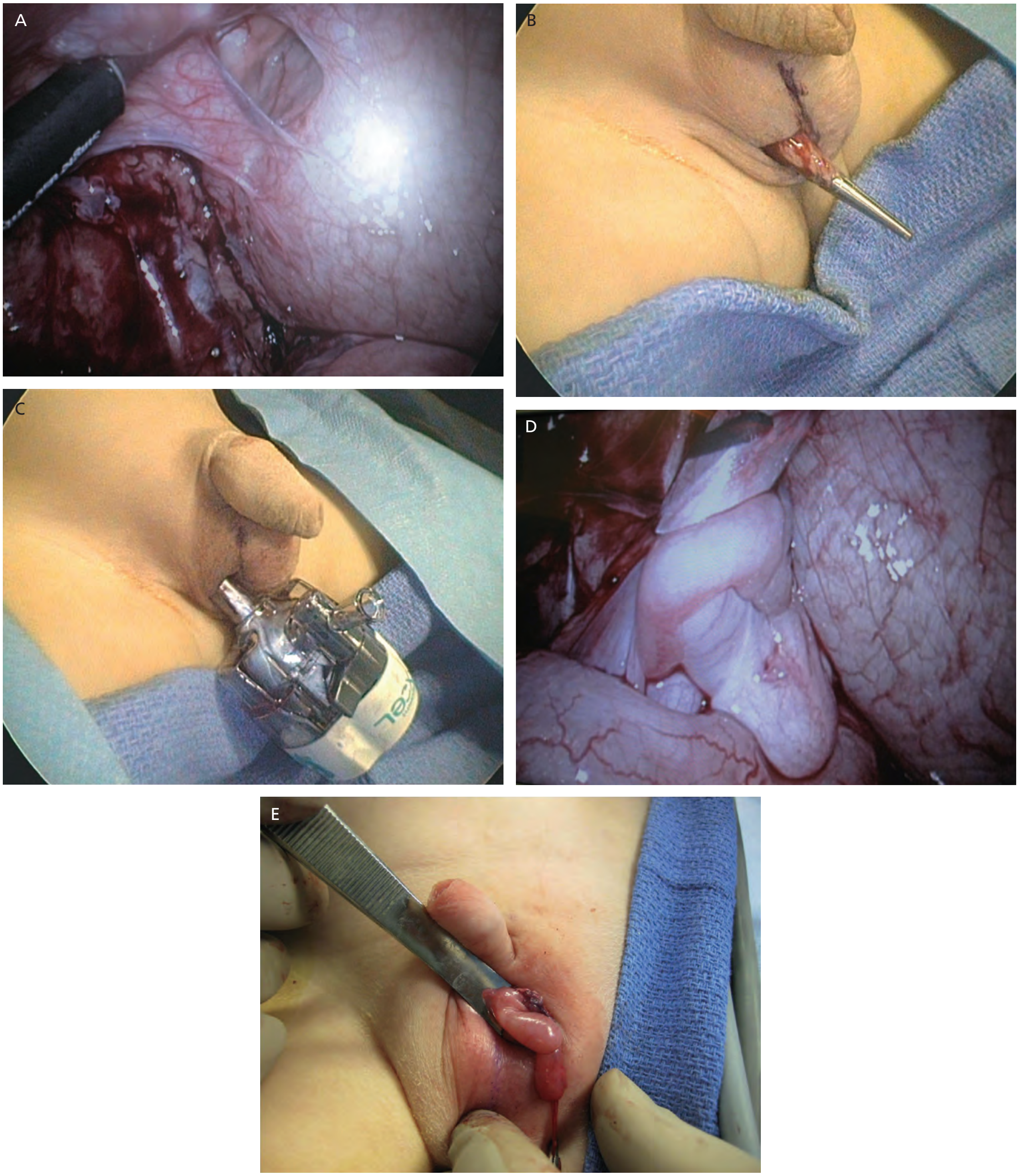

Figure 99.5 Development of the neohiatus and delivery of the testis. (A) Dissection between the lateral edge of the bladder and the medial aspect of the obliterated umbilical ligament. (B) Placement of the dissector through the neohiatus and over the pubis into the scrotum through the subdartos pouch. (C) A 5-mm port with a beveled end is passed retrograde from the scrotum, over the dissector, and into the abdomen. (D) The gubernaculum is firmly grasped through the scrotal port and the testis brought intrascrotal as the port is removed. (E) The testis is placed in proper orientation dependently into a subdartos pouch.

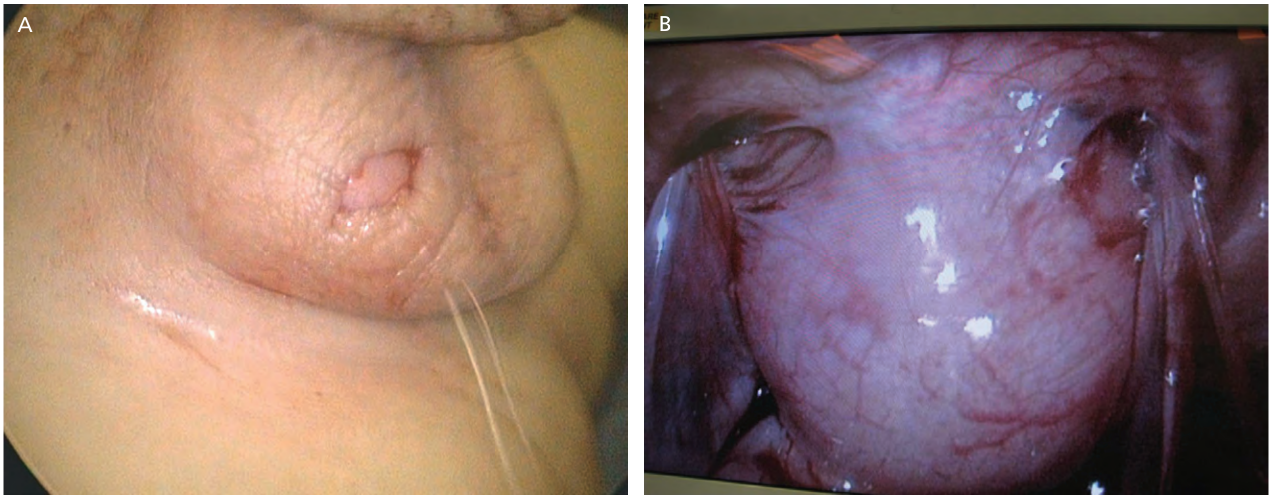

Figure 99.6 Final views of the laparoscopic orchidopexy. (A) Scrotal view with dependently positioned testis, and (B) within the abdomen following bilateral laparoscopic orchidopexy demonstrating tension-free passage of the triangle of peritoneum through the neohiatus.

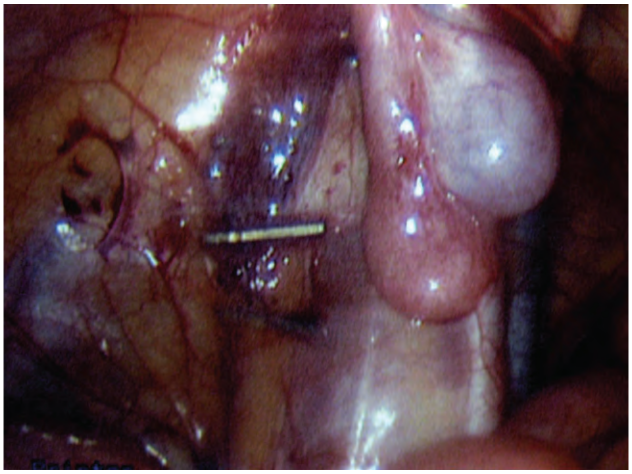

Figure 99.7 Intraoperative image of the area where clips were placed and division of the internal spermatic vessels was performed (Fowler–Stephens procedure).

Bilateral intra-abdominal testes

The child with bilateral nonpalpable testes poses a more complex clinical situation. The issue of a disorder of sexual differentiation needs to be considered and evaluated. The work-up of such a child is beyond the scope of this chapter. However, once it is established that such a diagnosis is absent, the next step in management is to determine whether testes exist and then the number of testes that are present. In boys with anorchia, basal levels of gonadotropins [follicle-stimulating hormone (FSH) more than LH] will be elevated. If one or two testes are present and Leydig cell function is normal, then hCG administration should stimulate testosterone production. Nevertheless, inspection of the abdomen to determine the number of testes is necessary regardless of the outcome of the hCG stimulation test as false-negative studies are not uncommon. In a series from the Children's Hospital of Philadelphia, bilateral intra-abdominal testes comprised less than 1% of the total cryptorchid testes, but 3.1% of nonpalpable testes and 15.3% of all intra-abdominal testes [61]. Chang *et al.* reported that among intra-abdominal testes, 25% were bilateral [58].

Laparoscopy plays an important role in diagnosing bilateral intra-abdominal cryptorchidism and in surgical correction. Cortesi *et al.* in 1976 reported using diagnostic laparoscopy to successfully localize bilateral intra-abdominal testes in one patient [1]. Ansari *et al.* in 2002 reported on single-setting management of bilateral cryptorchidism in a 30-year-old man [62]. Kaye and Palmer specifically addressed the laparoscopic management of bilateral intra-abdominal testes in 26 boys (aged 7–52 months, median 9 months) [63]. A staged procedure was decided upon for five of these boys (four for very high positions, one for medical reasons to reduce operative time) before any dissection took place. Of the remaining 21 boys, 16 had successful single-stage bilateral laparoscopic orchidopexies to achieve viable intrascrotal testes at 1-year follow-up; two boys underwent two-stage Fowler–Stephens laparoscopic orchidopexy and one boy required a secondary open orchidopexy to achieve satisfactory intrascrotal position (total 91%). Surgery was free of complication and performed as an ambulatory procedure with minimal blood loss. The authors advocated bilateral single-stage laparoscopic orchidopexy when possible. The testis that appears best suited for successful orchidopexy should be operated on first and then a decision made to proceed with the second testis. If viability of the first testis is questionable, then the authors advocated waiting about 3 months before proceeding with the second orchidopexy. If viability is not in question upon completion of the first orchidopexy, then the higher testis should be approached concurrently either as a single- or two-stage procedure (Fowler–Stephens) as indicated.

Conclusions

Laparoscopy has markedly improved the management of the nonpalpable testis. Diagnostic laparoscopy carries remarkable accuracy in determining whether a testis is present in the abdomen or whether the vanishing testis syndrome or an atrophic intra-abdominal testis exists. Although laparoscopy requires a 5-mm puncture and general anesthesia, the accuracy of this procedure exceeds that of the best imaging study, MRI, which also requires anesthesia, or open surgical exploration, which requires a larger incision as well as general anesthesia. Missing an intra-abdominal testis carries sufficient morbidity that accurate diagnosis is mandatory. Therapeutic laparoscopy in the form of orchidopexy can provide proper positioning of a viable testis more successfully than open surgery regardless of whether or not a Fowler–Stephens procedure is required. The laparoscopic approach allows for a better retroperitoneal mobilization and when ligation of the spermatic vessels is deemed necessary, can be done rapidly and simply with minimal incision and discomfort. Laparoscopic orchidopexy should be the procedure of choice for anyone familiar with laparoscopy. As current residents and pediatric urology fellows continue to incorporate laparoscopy into their training, open surgery for the nonpalpable testis will likely be relegated to historical interest.

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CHAPTER 100

Laparoscopic Exit: Specimen Removal, Closure, and Drainage

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Introduction

Laparoscopic surgery has well-defined benefits for the patient and has, over time, become accepted as a standard of care access strategy for the management of benign and malignant urologic diseases. Exiting the abdominal cavity is an important step after all laparoscopic procedures and safe exit after laparoscopic surgery requires a systematic approach. At the conclusion of every operation, a careful inspection of the operative field must be performed in order to evaluate for adequate hemostasis and adjacent organ injury. Improper removal and closure of laparoscopic trocars or hand-assist devices can be a source for postoperative complications, such as delayed bleeding, dehiscence, or postoperative hernia, and can lead to unnecessary patient morbidity. A distinct advantage of laparoscopy is the ability to view extraction incisions and device closure defects following repair. This affords the surgeon the ability to rule out immediate problems with the closure, such as excessive bleeding and entrapment of visceral structures.

Despite significant advances in laparoscopic technique and technologies, laparoscopic urologic surgery remains technically demanding. Unlike open surgery, at the termination of laparoscopic extirpative procedures, the urologist is often faced with the additional challenges of specimen retrieval and extraction. Laparoscopic specimen entrapment and extraction occurs at what is falsely considered the "termination of the procedure." During open surgery, after the specimen has been mobilized, it is simply lifted out of the larger incision, which has been made to achieve the surgical objectives. At this time the open surgical team is typically more relaxed, and may turn up the volume on what is commonly referred to as "closing music." In contrast, significant laparoscopic skill is required to entrap and safely extract laparoscopic specimens. It is imperative that during laparoscopic procedures, the "termination of the procedure" be strictly defined as the termination of skin closure and dressing placement. Taking a few minutes to focus on safe specimen entrapment and extraction may substantially reduce major morbidity.

This chapter will outline a systematic approach for exiting the abdomen and focus on the technology and techniques of specimen entrapment, extraction, drainage, and various methods of abdominal wall closure. The primary objectives are to minimize morbidity while maintaining the advantages of a minimally invasive surgical approach.

Specimen collection and types of device

Laparoscopic specimen removal includes small dimensions from trocar sites (often smaller than the specimen extracted), making specimen retrieval and extraction very challenging. Currently, there are a number of commercially available retrieval devices that facilitate specimen extraction (Table 100.1). Important characteristics to be evaluated in a retrieval device are the sac permeability, resistance, and stability within the abdominal cavity [1]. Commercially available laparoscopic bag retrieval systems consist of single-use specimen collection bags

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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Table 100.1 Laparoscopic specimen retrieval devices.

Device	Characteristics
LapSac® (Cook Urological, Spencer, IN, USA)	Made of nylon with polyurethane inner coating Requires 10–12-mm trocar for insertion Does not self-open Only sac with data to support use with intracorporeal morcellation
LapBag® (Bard-Angiomed, Salt Lake City, UT, USA)	Made of nylon with polyurethane inner coating Has special introducer for insertion Requires 10–12-mm trocar Self-opening sac
Extraction Bag® (Karl Storz, Tuttlingen, Germany)	Made with transparent polyurethane Special introducer for insertion Requires 10–12-mm trocar for insertion Self-opening sac
Endobag® (Covidien, Norwalk, CT, USA)	Transparent polyurethane Single use Requires 10–12-mm trocar for insertion Does not self-open
Endopouch® (Ethicon Inc, Somerville, NJ, USA)	Made of transparent polyurethane Single use Special introducer Requires 12-mm trocar Self-opening
EndoCatch® (Covidien, Norwalk, CT, USA)	Transparent polyurethane Special introducer Requires 10–12-mm trocar for insertion Self opening

that are sterile. These entrapment devices facilitate removal of the specimen without contamination of the abdominal cavity or extraction wound.

Collection devices

Pure sacs

Laparoscopic retrieval bags are primarily made of polyurethrane and are available in a variety of sizes. The bags are introduced through a trocar that is at least 10 mm in size using a blunt laparoscopic instrument. The bag is fully opened in the abdomen using blunt-tipped instruments so that the specimen can be properly introduced. Closure of the bag involves tightening the purse-string mechanism at the top of the bag in order to form a complete seal. Examples of this device include the LapSac (Cook Urological, Spencer, IN, USA) and the Endobag (Covidian, Norwalk, CT, USA).

Sacs with mechanisms

Retrieval bags such as the EndoCatch bag (Covidien) feature a polyurethane specimen bag collapsed within a long cylindrical tube, some of which can be introduced through a 10-mm trocar. The bag is deployed in the abdomen by opening a continuous metal ring that is attached to the top of the bag. The specimen is deposited inside the bag using blunt-tipped instruments and the purse-string mechanism is closed by pulling on the end of the suture, which is attached to a small plastic ring outside the body. This closes and seals the sac, and the string is cut in order to free the bag from the metal ring and introducing instrument.

Extraction incisions

Options at the termination of extirpative urologic procedures include intact extraction and specimen morcellation. For intact extraction, the specimen can be removed from the body through a variety of abdominal incisions. An extension of an existing trocar incision is often used, which prevents an entirely new incision from being created for removal. While expedient, extension of an existing trocar site should be done with caution as certain incisions are associated with higher rates of complications. Elashery *et al.* reported five of 29 with extraction site hernias after laparoscopic radical nephrectomy and extension of an existing trocar incision [2]. Tisdale *et al.* compared extraction sites formed by an extended trocar site to a Pfannenstiel incision in patients undergoing laparoscopic radical nephrectomy, nephroureterectomy, and donor nephrectomy [3]. An incisional hernia developed in three (2.9%) patients who had an extension of a trocar site for extraction; no patients receiving a Pfannenstiel extraction developed a hernia. However, the closure method was not documented in either extraction site group. Bird *et al.* retrospectively analyzed patients undergoing laparoscopic radical nephrectomy and intact specimen retraction through three different incision sites (umbilical, paramedian, and lower quadrant) [4]. A total of 181 nephrectomies were performed. Four patients developed a hernia, all of which occurred through a paramedian incision. In addition, body mass index (BMI) was a significant factor related to the development of an incisional hernia.

Other extraction options include removal of the specimen through a new midline incision, which many surgeons prefer due to the familiarity with midline abdominal wall anatomy. Ideally, this approach is done with a small incision near the umbilicus (depending on specimen size), which is cosmetically more appealing. Specimen removal can also be performed through a low Pfannenstiel incision, which provides a good cosmetic result, but requires a new incision. The surgeon must plan in advance for this type of incision by ensuring that the patient is positioned adequately before the surgery, so that access to the lower abdominal wall can be obtained for specimen removal. When compared with an extended trocar extraction incision, Pfannenstiel incisions have demonstrated significantly less postoperative pain medication requirements (23.7 mg vs 47.3 mg morphine equivalent) and a reduced length of hospital stay (2.84 days vs 3.37 days) [3].

Specimen morcellation

Morcellation is the fragmentation of organs into smaller pieces, and is classically performed after the specimen has been entrapped and prior to removal in order to maintain a small abdominal wall incision. The practice, while an accepted standard of care, remains controversial, particularly for malignant disease. The primary goals of specimen morcellation are to safely maintain the minimally invasive nature of the laparoscopic approach and oncologic efficacy. However, controversy exists regarding patient safety and the quality of tissue to be examined for final pathology. In order to perform morcellation safely, the procedure must be done under direct endoscopic vision. Safe morcellation without tissue spillage or entrapment bag perforation is only typically done in the LapSac as it is the most durable entrapment sac, and it is the only entrapment sac which has been tested for impermeability [5, 6].

A technique of “modified morcellation” in which a 2.5-cm incision is used and the specimen is morcellated *ex vivo* under direct vision has been described. With modified morcellation, entrapment can be expedited and facilitated by the application of a less durable entrapment sac (described with the EndoCatch sac), and reasonable histopathology can still be gained due to the larger fragment size that can be achieved with this technique [7]. A limited number of case reports with tumor seeding and cancer recurrence have been reported after morcellation [8]. Possible contributing factors include using a retrieval sac that is not specifically designed for morcellation or unrecognized micro-perforations in the sac itself.

Another potential issue with specimen morcellation is the inability to accurately document pathologic tumor stage during an oncologic procedure. However, studies evaluating oncologic results of morcellation have shown that this technique did not significantly impact the ability to determine pathologic stage [9, 10]. In addition, recurrence rates were shown to be similar to those following intact specimen retrieval [11].

Systematic approach for exiting the abdomen after laparoscopic procedures

Step 1: Inspection

After completion of the surgical procedure, meticulous inspection of the surgical bed and surrounding structures is performed. Due to the limited haptic feedback associated with laparoscopy, it is essential that careful evaluation for hemostasis and adjacent organ damage is carried out. Organs and structures outside the surgical field can occasionally be damaged during surgical mobilization or retraction. In laparoscopic renal surgery, both the liver and spleen must be mobilized in order to gain perfect access to the kidney. The liver is often retracted cephalad using a locking–grasping instrument. Inspecting the entire surface of these organs is necessary to exclude injuries that may contribute to postoperative bleeding. Similarly, the colon and duodenum are mobilized medially. These bowel structures must be inspected following these maneuvers for potential lacerations or cautery injury. Laparoscopic procedures performed in the pelvis necessitate inspection of the small bowel, sigmoid colon, and pelvic vasculature to confidently rule out injury.

Following organ inspection, the surgical field must be examined for hemostasis. Although arterial bleeding is usually identified immediately, the pneumoperitoneum of 15–20 mmHg provides a venous tamponade effect that can obscure venous hemorrhage. Therefore, all portions of the surgical field must be examined under low insufflation pressure (≤5 mmHg).

Following a comprehensive evaluation of the abdominal and/or pelvic cavity, body wall access sites must be inspected for excessive bleeding. Trocars should be removed under direct vision and monitored briefly for the presence of bleeding. Special attention should be given to the trocar placed at the initial site of access as this is the only trocar that is not placed under direct vision. Bleeding from a trocar site can be controlled by placing an absorbable hemostatic suture (Vicryl or Dexon) at the trocar site with the aid of endoscopic vision. Other methods include the use of a Carter–Thomason device (Inlet Medical Inc, Eden Prairie, MN, USA). This device is also used for closure of the abdominal wall fascia and is described in detail later in this chapter. In most cases, bleeding from the abdominal wall can be controlled by these measures. However, if bleeding cannot be managed endoscopically, the trocar incisions should be extended at the skin level to allow for better access vision for proper hemostatic control.

If an extraction incision has been made for specimen removal, this incision should be endoscopically inspected to assure that no intra-abdominal contents have been incorporated into the closure and that there is no bleeding from this site.

Step 2: Trocar extraction, desufflation, and site closure techniques

Trocar site closure is dependent on both the size of the defect and the type of trocar used. Traditional "cutting" trocars have a sharp blade that penetrates the body wall, creating a defect in the fascia that is the same size as the diameter of the trocar itself. More recently, trocars that spread abdominal wall tissue and fascia ("dilating" trocars) create a defect by either axially or radially spreading the fascia. These "dilating" trocars create a fascial defect that is approximately half the diameter of the trocar. Therefore, even when 12-mm dilating trocars are placed, fascial closure is not necessary in healthy adults. In the pediatric population, all trocar sites should be meticulously closed regardless of the size or nature of the trocar being applied.

Shalhav *et al.* compared fascial nonclosure after the use of dilating trocars with fascial closure after the use of cutting trocars. No evidence of hernia formation occurred in either group at a mean follow-up of 4.8 months [12]. Liu and McFadden reported on results of 180 fascial sites after the placement of dilating trocars. After a median follow-up of 11 months, no hernias were documented [13]. Patients with poor quality fascia (history of abdominal wall herniation, steroid use, poor nutritional status) and pediatric patients should have all trocar fascial sites closed. While our team routinely leaves the fascia open after application of dilating trocars, we do perform a "digital inspection" (gentle palpation of the trocar site with a finger to assess the defect) to assure that the fascial defect has not expanded. If the fascial defect seems larger than usual, we do not hesitate to close the defect using the techniques described below.

Desufflation of the abdomen

Following the removal of all trocars under direct vision and prior to wound site closure, the abdominal cavity should be decompressed in order to eliminate the pneumoperitoneum. It has been suggested that residual gas in the abdomen may contribute to pain or ileus in the postoperative period. Desufflation is accomplished by removing all trocars and applying gentle pressure to the abdomen to expel the gas.

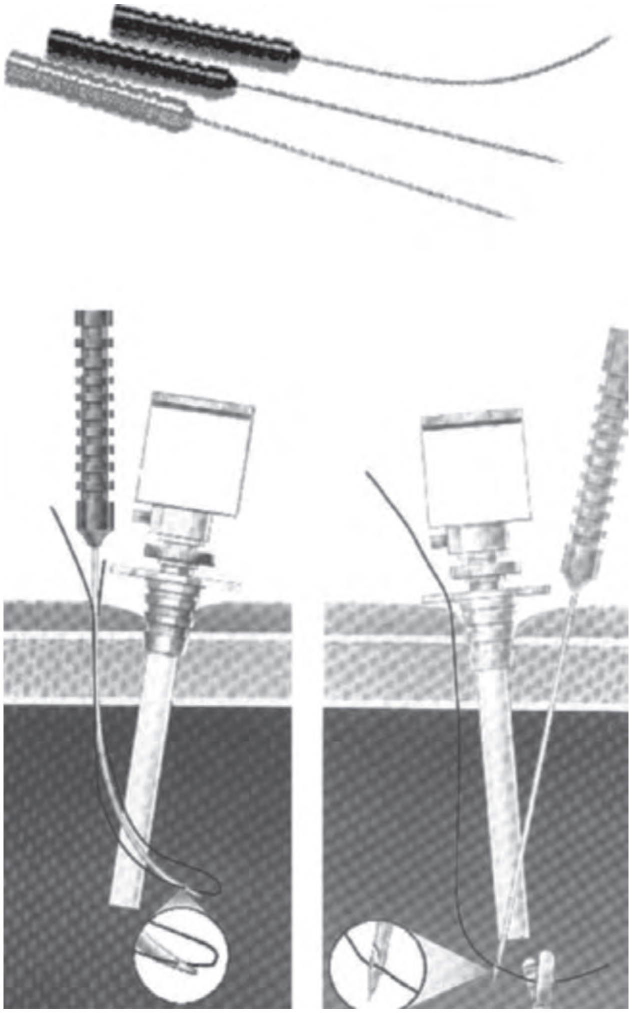
Closure techniques

Intracorporeal manipulation under direct visualization

The Maciol suture needle set (Core Dynamics Inc, Jacksonville, FL, USA) consists of a set of three needles: two black-handled suture introducers (straight tip and curved tip) and a gold-handled suture retriever. An absorbable suture is placed through the hole in one of the introducer needles, which is placed percutaneously through the abdominal wall while the trocar remains in place [14]. The retrieval needle is placed 180° from the initial suture passage and grasps the end of the suture. The straight introducer needle is assisted by a laparoscopic grasper in order to place the end of the suture into the retriever (Figure 100.1). Next, the trocar is removed and the fascia is pulled and tied together for closure.

The Grice needle (Ideas for Medicine Inc, Clearwater, FL, USA) is loaded with an absorbable suture and inserted at an angle along one side the trocar to be closed (Figure 100.2). A grasper is used from a different trocar to grasp the suture from inside the abdominal cavity. The Grice needle is then placed in the same manner along the other side of the trocar and the suture is regrasped with the Grice [14]. The Grice device with the grasped suture is pulled out through the abdomen and tied under direct vision.

Conlon *et al.* developed a method of closure using a 14G angiocatheter, which is placed on one side of the trocar defect [15]. Once this is visualized laparoscopically, the obturator can be removed and a 24-inch 0-absorbable suture is placed through the obturator and into the abdomen. The angiocatheter is then placed on the other side of the fascial edge. A 36-inch 0-absorbable suture is looped and placed through the catheter lumen. The initial free end of the suture is placed into the loop and the angiocatheter is removed. The suture is tied to itself, closing the defect (Figure 100.3).



1 2

Figure 100.1 Maciol suture needle set (Core Dynamics Inc, Jacksonville, FL, USA) and technique (reproduced from Shaher [14], with permission).

The EndoClose suture device (Tyco Auto Suture International Inc, Norwalk, CT, USA) is a spring-loaded disposable device, which is loaded with a suture prior to being introduced into the abdomen in the gap between the trocar and skin edge. The suture is released and the device is placed 180° from the first pass. A grasper is used through a second port to place the suture in the open notch of the EndoClose device (Figure 100.4). The device is pulled out together with the trocar. The suture is then tied down to approximate the fascia.

Extracorporeal manipulation under direct visualization

The Carter–Thomason needle point suture passer (Inlet Medical Inc) consists of a cone-shaped plastic guide and the Carter–Thomason metal needle passer and grasper (Figure 100.5). The device is placed into the trocar defect initially. Next a 0-absorbable suture is placed in the needle passer, which traverses the abdominal wall and peritoneum through a hole in the top of the cone-shaped introducer. This process is performed under direct vision with the laparoscope during closure. The suture is then released and the grasper enters the abdomen through a second predrilled hole in the introducer. The suture is grasped and pulled out of the body and the suture guide is removed. Finally, the suture is tied, bringing the fascia together (Figure 100.6). Elashry *et al.* randomized 95 trocar-site closures to one of eight different types of closure devices. The Carter–Thomason was significantly faster than any other closure method (mean closure time of 2.5 min) with the exception of standard hand closure (1.9 min) [16]. This device also had no closure-related complications.

The Tahoe surgical instrument ligature device (Tahoe Surgical Instruments Co, San Juan, Puerto Rico) is disposable and includes a handle with a locking button and two hollow metal needles (2 cm apart) that are used for passing and retrieving sutures (Figure 100.7). The trocar is removed and the needles on the device are placed into the defect through an introducer disc, which pierce both fascial edges simultaneously. An absorbable suture is placed in the delivery needle. The handle is depressed, which releases a metal retrieval loop from the hollow retrieval needle. The suture is passed into the metal loop and the entire device is removed, allowing the suture to traverse the fascial defect for closure (Figure 100.8).

The Puncture closure device (Progressive Medical, St Louis, MO, USA) is a disposable 10-mm instrument with a recessed right-angled needle that can be exposed by rotating a dial at the top of the instrument. The device is introduced through a 12-mm trocar and visualized in the abdomen. The knob is rotated to expose the needle and the device is pulled up out of the port, which causes the needle to draw up through the fascia and subcutaneous tissues. An absorbable suture is loaded through the hole in the needle. The device is then pushed back into the abdomen, rotated 180°, and again brought up through the opposite side of the abdominal wall by removing the instrument from the port. The device is placed back into the abdomen and the needle mechanism is closed, followed by removal of the device (Figure 100.9). The trocar is then removed and the suture is tied approximating the fascia.

Standard technique

In traditional hand-sutured closure, the trocar is removed from the abdominal wall under direct vision while examining the edges of the fascia. The fascial defect is identified and closed in an interrupted or running fashion with an absorbable suture (0-Vicryl or 0-Dexon) on a CT-1 needle. Alternatively, and with

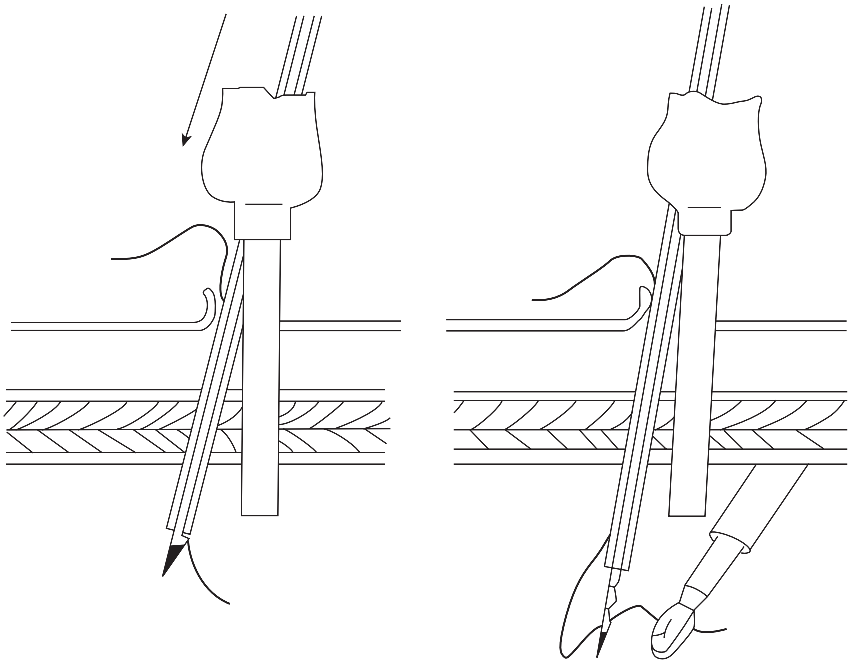


Figure 100.2 Grice needle (Ideas for Medicine Inc, Clearwater, FL, USA) (reproduced from Shaher [14], with permission).

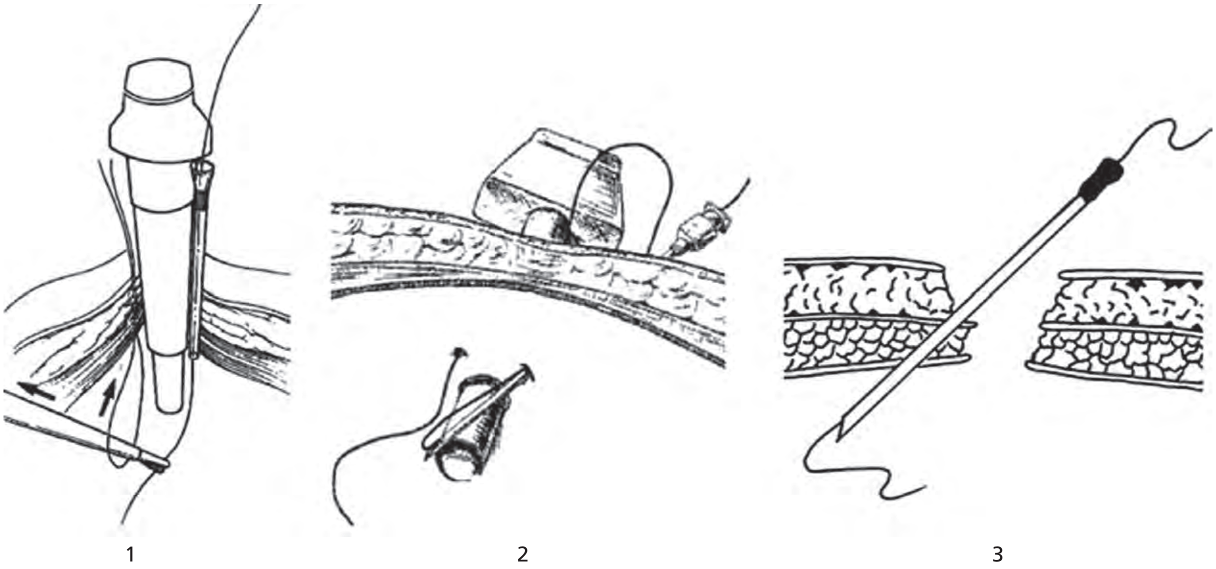


Figure 100.3 Angiocatheter closure (reproduced from Shaher [14], with permission).

smaller extraction sites, a figure-of-eight interrupted suture can be used by first grasping both edges of the fascia with Kocher clamps. A standard suturing technique is appropriate for thin patients where the fascia is easily identifiable. However, in patients with a large amount of subcutaneous tissue, the fascia may be difficult to see and isolate, which can lead to an inadequate closure.

Step 3: Closure of hand-assist devices and organ extraction sites

An organ extraction site or hand-assist port is usually closed prior to the removal of laparoscopic trocars. These incisions are closed in a manner similar to that used for a standard incision in an open surgical procedure. The fascia is closed either in a running fashion or

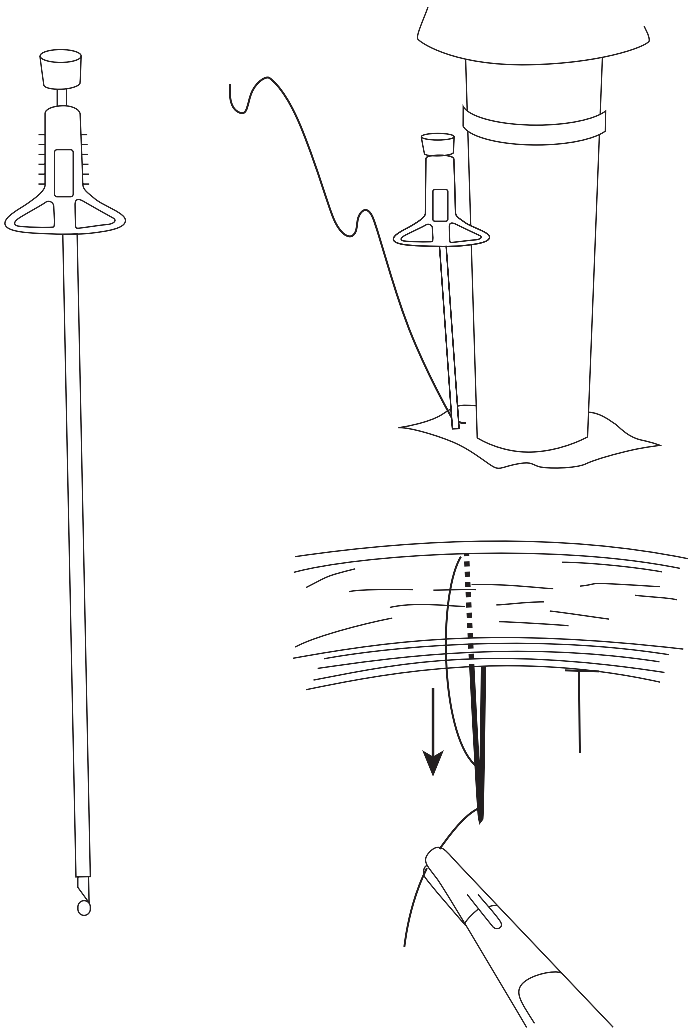


Figure 100.4 EndoClose suture device (Tyco Auto Suture International Inc, Norwalk, CT, USA) (reproduced from Shaher [14], with permission).

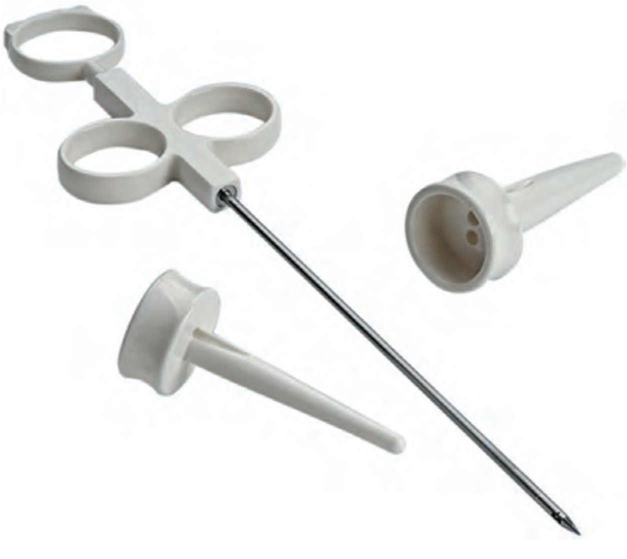


Figure 100.5 Carter–Thomason closure device (Inlet Medical Inc, Eden Prairie, MN, USA).

with interrupted figure-of-eight sutures. Following wound closure, the abdomen is reinsufflated to examine the integrity of the closure site and to make sure that abdominal vicera have not been incorporated during the closure. Finally, each trocar is removed under direct vision.

Step 4: Skin closure

Hochberg *et al.* have described the principles of skin closure [17]. Sutures placed in the dermis provide tensile strength to the closure, while sutures in the epidermal layer coapt the skin edges. Edges must always be everted during closure and be tension free. Careful attention to these principles will lead to a cosmetically acceptable result with a high level of patient satisfaction.

Port-site skin wounds may be closed with different techniques, but most commonly with a subcuticular closure with or without the use of transcutaneous skin

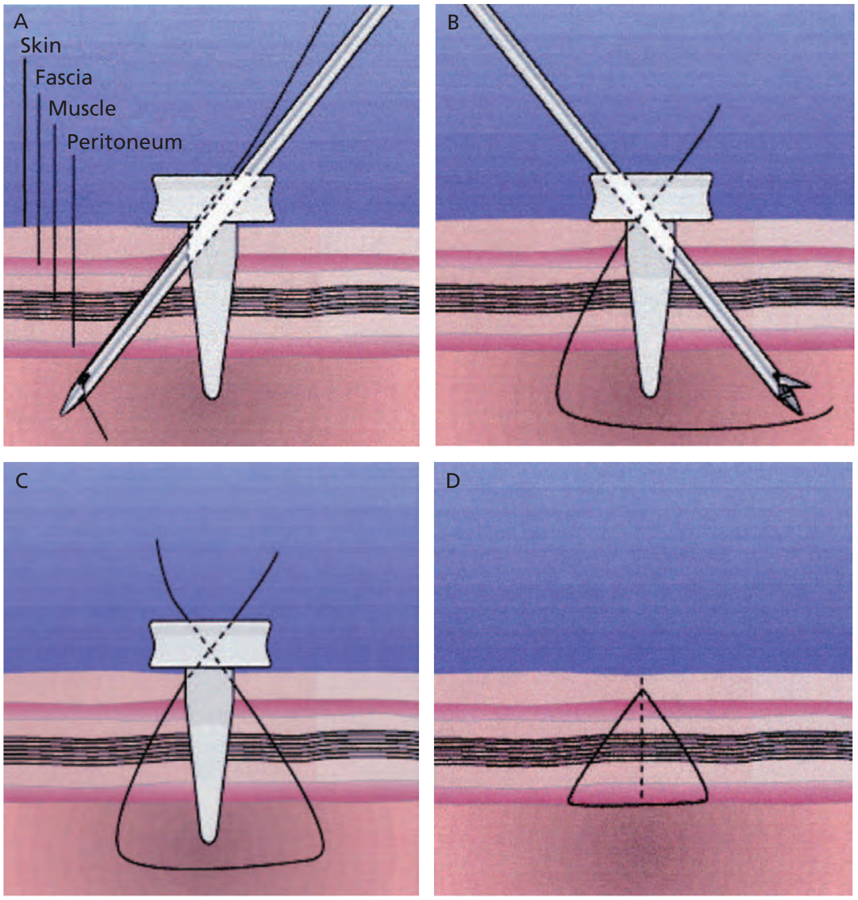


Figure 100.6 (A–D) Carter–Thomason closure.

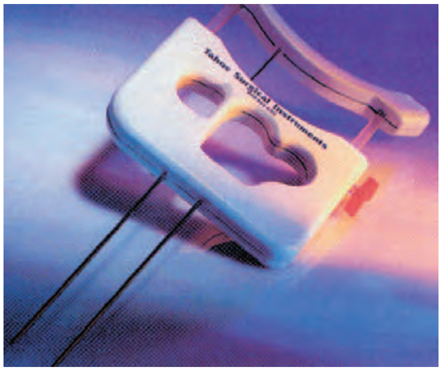


Figure 100.7 Tahoe ligature device (Tahoe Surgical Instruments Co, San Juan, Puerto Rico).

tape (steri-strips). All port sites should be irrigated thoroughly following removal and prior to closure. Subcuticular closure with a 3-0 or 4-0 absorbable suture will approximate the skin edges adequately. All 12-mm trocar sites must be closed with a subcuticular suture. Smaller port sites (5 mm) are usually closed in the same manner; however, these sites may simply be closed with an adhesive steri-strip that functions to approximate the skin edges. Following skin closure, mastisol liquid adhesive (Ferndale Laboratories Inc, Ferndale, MI, USA) and steri-strips are placed over the incisions for additional re-enforcement.

Skin adhesives

Fast-acting adhesives may be applied to human tissue for wound closure. These adhesives are formed by an association of a monomer and a plasticizer that forms a flexible bond with a breaking strength comparable to that of a 5-0 monofilament suture. The adhesives dry quickly (<1 min) and are used for small incisions such as traumatic skin lacerations and laparoscopic port-site wounds [18]. Dermabond (2-octyl cyanoacrylate; Ethicon Inc, Somerville, NJ, USA) and Indermil (N-butyl cyanoacrylate; Covidien, Mansfield, MA, USA) are examples of commercially available adhesives that are applied following a subcuticular skin closure and do not require the placement of steri-strips or postoperative dressings.

Dermabond has been compared to a running subcuticular closure using a 4-0 Monocryl 25 (Ethicon Inc) in a prospective randomized trial. Closure with Dermabond was significantly faster than standard closure (155 s vs 286 s, respectively); however, several wound separations were documented in the Dermabond group. There were no wound-related complications with the standard subcuticular closure [19]. A meta-analysis of four randomized studies with 404 patients comparing skin adhesives with suturing for the closure of laparoscopic port-site wounds revealed no difference in wound infection, wound dehiscence, and patient satisfaction [20]. Perry *et al.* reported a severe local allergic reaction to Dermabond after mastectomy [21]. Although these adhesives seem to be a safe and convenient option, additional studies comparing them to standard closure techniques are needed.

Step 5: Postoperative drains

The decision on whether or not to place a surgical drain after laparoscopy is based on the same principles as open surgery. A surgical drain may be indicated in a variety of situations, including fluid accumulation in a large potential space (surgical bed or subcutaneous space), drainage of infected or necrotic tissue, management/prevention of a urinary fistula, and local management of a delayed hemorrhage. Drain placement in most urologic procedures functions to help identify urinary fistulas or "leaks." Procedures such as laparoscopic partial nephrectomy, nephroureterectomy, and radical prostatectomy carry the risk of a postoperative leak that can be identified by either a high volume of output from a drain and/or the presence of an elevated drain fluid creatinine.

Active surgical drains are closed system drains that exert a negative low pressure, which removes fluid gradually. The drains consist of a collapsible reservoir and work by self-suction. Examples include the Jackson–Pratt drain, which is a flexible rubber bulb (100 mL) with a small rubber plug connected to an internal drainage tube (Figure 100.10). Opening the plug and squeezing the air out of the bulb followed by plug replacement creates the self-suction system [14]. A Hemovac or Davol drain is a larger closed-system drain (400 mL), which has a collapsible disc shape with a rubber stopper that works in the same manner as the Jackson–Pratt drain; however, the tubing for Hemovac drains is thicker and less flexible compared with the Jackson–Pratt drain (Figure 100.11). The tubing for active drains may be milked or "stripped," which involves stabilization with one hand of the portion of the tubing that is closest to the patient's body. The other hand pinches the tubing to move blood clots and tissue through the tubing, thus facilitating improved suction.

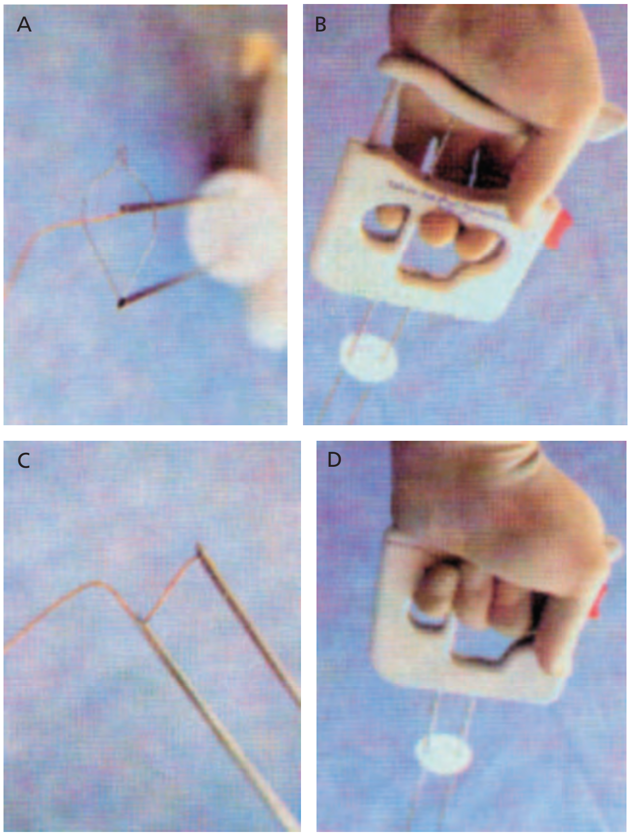


Figure 100.8 (A–D) Tahoe device closure technique.

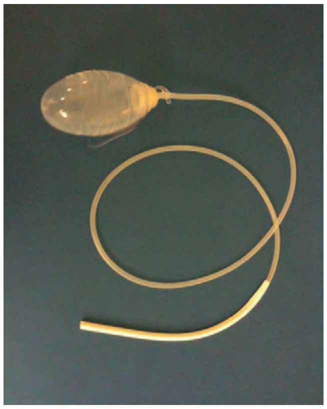


Figure 100.10 Jackson–Pratt drain.

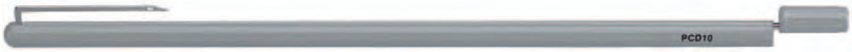


Figure 100.9 Puncture closure device (Progressive Medical, St Louis, MO, USA).

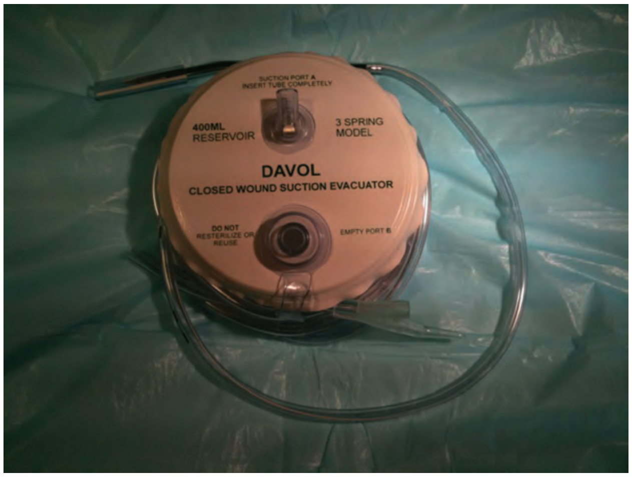

SUCTION PORT A INSERT TUBE COMPLETELY
400ML RESERVOIR
3 SPRING MODEL
DAVOL
CLOSED WOUND SUCTION EVACUATOR
DO NOT RESTERILIZE OR REUSE
EMPTY PORT B

Figure 100.11 Hemovac drain.

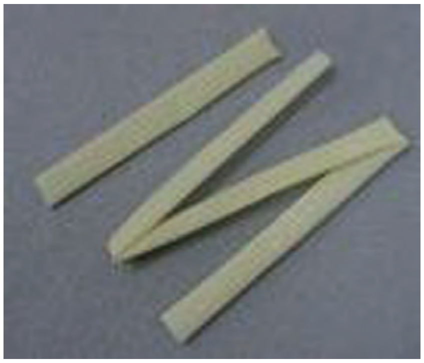


Figure 100.12 Penrose drain (courtesy of Dr. Andrew Bidwell. Veterinarian 121 clinical practice website “wounds and wound care lesson” http://loudoun.nvcc.edu/vetonline/vet121/wound_care.htm accessed June 2011).

Passive drains provide an exit port for fluid, blood, purulent material, and debris, and act via gravity and capillary action. A Penrose drain is a common passive drain that is made of soft latex tubing that is open at either end (Figure 100.12). Penrose drains are often used when the fluid to be removed is too viscous for a closed self-suction drain. Following placement, the drain is sutured into place at the skin level to prevent retrograde migration into the abdominal cavity. A safety pin is commonly used to further prevent migration. The distal end of the drain is covered with drain and dressing sponges to contain the drainage in the postoperative period. Prior study has demonstrated that passive drains are thought to carry a higher risk of infection because they are an open system and allow the migration of bacteria directly into the body. Closed-suction drains are thought to perpetuate a urinary fistula postoperatively and possibly lead to delayed hemorrhage with removal of the drain. Sanchez-Ortiz *et al.* performed a retrospective study on 197 patients undergoing open partial nephrectomy and placement of a retroperitoneal drain to determine differences in postoperative drain-related complications, such as a persistent urinary fistula, delayed hemorrhage, wound infection, and perinephric abscess. Two surgeons placed drains in all cases and the type of drain placed was left to the discretion of each surgeon (37.6% Penrose and 62.4% closed suction). There were no clinical differences between the groups in duration of drainage, tumor size, patient age, BMI, blood loss, or operative time. Although there was variation in the incidence of complications by drain type, none was statistically significant [22].

Common complications with either type of drain include skin infection or inflammation, perinephric wound infections, bleeding, pain, loss of the drain, and retrograde drain migration. Therefore, the risks and benefits of drain placement must be considered after each operation and a drain should be removed as soon as its function is no longer necessary.

Conclusions

Successful laparoscopic surgery depends on a safe and effective method of specimen entrapment and removal, and proper closure of the abdominal wall. A systematic approach to the laparoscopic exit starts with a diligent visual inspection of the operative field and trocar sites for excessive bleeding, organ injury, and organ entrapment. Proper closure of the abdominal fascia and skin can be performed with a variety of hand-suturing techniques as well as laparoscopic closure devices, which allow for direct visualization either during or immediately following the closure. Basic knowledge regarding the use of retroperitoneal drains (indications and complications) is also helpful in achieving a successful result after laparoscopy by limiting the number of postoperative complications.

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CHAPTER 101

Complications in Urologic Laparoscopy

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Introduction

While laparoscopy has decreased the morbidity of many urologic procedures, the solutions to complications arising in the minimally invasive environment frequently have no direct open surgical counterpart. For example, laparoscopic access is often obtained through a variety of initially blind punctures where viscera and blood vessels are susceptible to unique injuries. The insufflated abdomen presents specific potential physiologic complications, complex instrumentation can malfunction catastrophically, and inadvertent injury can occur outside the laparoscope's field of view due to unobserved instrument gestures. Laparoscopy therefore requires a specialized knowledge base, and demands a unique set of troubleshooting skills. Whereas textbooks have been devoted to laparoscopic complications, this chapter will cover the main areas pertinent to the urologist in training, as well as for the practicing urologist wishing to broaden their knowledge.

Since urologic laparoscopy is no longer in its infancy and surgical complexity has increased, admonitions about complications from only a decade ago may no longer be appropriate. For example, open conversion is less often required for the contemporary surgeon than it was in the past (early series prior to 2000, conversion as high as 2.1% [1]). While the threshold to convert must remain low, and the window to expeditiously address an evolving complication is short, the options and expertise to intervene without making an incision have expanded. The surgeon must exercise particular care during the learning curve; multiple studies in the urologic [2, 3] and general surgical literature [4] have demonstrated an inverse relationship between surgeon experience and complication rates.

Complications will be organized by major category: (1) access, (2) physiologic, (3) patient positioning, (4) end-organ (vascular, bowel, solid organ), (5) postoperative, and (6) miscellaneous. Where appropriate, complications pertaining to specific urologic procedures will be highlighted. Since robotic techniques have essentially duplicated laparoscopic counterparts for all procedures, all complications discussed herein and their management are generalizable to robotic surgery. The classification schema proposed by Clavien–Dindo will not be specifically reviewed, but the reader is urged to review this separately [5].

Access complications

Regardless of the method to gain initial deliberate entry into the peritoneal (or retroperitoneal) cavity, access remains a significant source of morbidity and potential mortality. The incidence of any type of access injury ranges from 5 in 10 000 to 3 in 1000 [6]. In a recent literature review of 41 articles, including almost 700 000 procedures for which Veress needle access was used, 1575 (0.23%) injuries occurred [7]. The majority (92%) of these injuries were minor. Although the risk of access injury is low, it is not negligible, and a surgeon is statistically likely to encounter several over the course of a career.

The following access techniques are available:

Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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- *Veress needle (closed entry)*, whereby a hollow needle with a retractable blunt tip is passed across the abdominal wall. Upon transperitoneal entry, the blunt cannula springs back into place, theoretically blunting the needle tip. Insufflation is then carried out through the needle.
- *Hasson (open entry)*, whereby access is gained via a mini-laparotomy approach and all layers are entered sharply [8].
- *Optical trocar*, a camera-guided approach where the camera sits within the trocar's transparent conical-tipped obturator, and all layers of the abdominal wall can be seen as the trocar is advanced [9]. This technique can be employed alone in a desufflated abdomen or following initial insufflation via a closed (Veress) needle.
- Other techniques, less commonly used in urology, include radially expanding trocars and direct trocar insertion.

A 2008 Cochrane literature review comparing open and closed entry techniques found that there was insufficient evidence to recommend one technique over another [10]. No technique is foolproof. Experts acknowledge, however, that a prospective study powered to detect a meaningful difference would require thousands of patients and is unlikely to be organized. Generalized under-reporting of complications further hampers attempts to define the true incidence of entry complications. However, a careful review of smaller studies reveals some take-home points. The incidence of vascular injury is probably higher with closed techniques [11]. Bowel injury is equally likely with open and closed entry techniques [12], but there may be a higher chance of immediate diagnosis with an open technique, since the injured bowel is directly visualized. Even so, delayed diagnosis of bowel injury has occurred following open access as well [13].

The nuances of safe access are highly subject to individual surgeon preference. As such, evidence-based literature only goes so far, and there is no substitute for hands-on beside training. In our opinion, for instance, Veress needle safety checks, such as aspiration and saline drop, can provide valuable clues when performed correctly and in conjunction with verifying a low opening pressure (ideally < 9 mmHg). A published report on this matter, however, concluded that the ancillary needle checks provided little useful information apart from opening pressure [14]. The literature must be interpreted with caution in this arena, since the most important factor in gaining safe access is surgeon familiarity and mastery of a given approach.

Flexibility to use a different technique when called for is crucial. When the surgeon encounters difficulty gaining access by any approach, the admonition to *change something* is prudent. A quote widely attributed to Einstein captures this concept: "The height of insanity is repeating the same thing over and over and expecting a different result." Stubborn repetition of the same maneuver invites complications. In a difficult access situation, careful reassessment of landmarks, checking for faulty equipment, and evaluating approach angles, can make all the difference. The trocar design must not create false reassurance, as even shielded trocars have not been shown to decrease access injuries. Also, be aware that in obese patients, reliable surface landmarks, such as the association between the umbilicus and aortic bifurcation, are lost.

Table 101.1 Preventive guidelines for laparoscopic access.

- Prior to skin incision, ensure that you have a working camera, insufflation, cautery, and laparoscopic suction
- Choose an entry site at a safe distance from prior scar, as underlying adhesions may be present
- With multiple prior abdominal surgeries, strongly consider open (Hasson) access.
- If a Veress needle is chosen, decide *a priori* on the number of "attempts" you will allow before switching to an open access technique (we recommend three at most). Complications increase as attempts increase [11]
- If you believe that elevating the abdominal wall is important, elevate the fascia (with a traction suture, Kocher clamp, or hand grasping and lifting the abdominal wall); do not elevate the skin only, as this will *increase* the distance to the peritoneal cavity
- Make sure Foley bladder decompression and orogastric tube stomach decompression have been instituted (especially in the pediatric population)
- Ensure anesthesia has achieved complete muscle relaxation. A possible cause of high opening pressure (Veress access) other than preperitoneal needle placement is incomplete patient relaxation
- After the trocar has been placed, look in with the camera immediately. If vascular injury has occurred, the window for diagnosis and intervention is short. Do not waste precious time cleaning the camera lens *prior* to your first look inside

The preventative guidelines in Table 101.1 are not data driven, but rather based on our experience. They are applicable for all types of laparoscopic types of access.

Physiologic complications

Pneumoperitoneum is associated with potential complications and physiologic alterations both from its mechanical compressive effects on blood vessels and viscera, and by its potential entry into the bloodstream and subcutaneous tissues. Carbon dioxide is utilized because it is widely available, noncombustible, colorless, and readily absorbed. An unfortunate by-product of its favorable diffusion properties is the potential to decrease blood pH with prolonged absorption. Patients with severe pulmonary disease in whom the ability to counteract acidosis with hyperventilation is impaired may have a relative contraindication to laparoscopy [15], but this is rarely encountered clinically.

While other pulmonary changes are best considered expected alterations rather than complications, they warrant mention nevertheless. Metabolic acidosis from hypercapnia can typically be measured in the form of expired CO_2. With mechanical ventilation, the clinical consequences are typically insignificant [16]. The mechanical compressive effects of pneumoperitoneum on the diaphragm causes increased intrathoracic pressure, increased peak airway pressure, and decreased vital capacity.

Hemodynamic effects of pneumoperitoneum are variable and difficult to generalize [16], but a recent prospective study by Meininger *et al*. thoroughly assessed this question by studying 10 patients undergoing robotic prostatectomy using a central venous catheter in place [17]. They were able to accurately measure cardiac output using thermodilution, cardiac index (CI), heart rate, mean arterial pressure (MAP), systemic vascular resistance (SVR), and central venous pressure (CVP), and correlate these with Trendelenburg position as well as pneumoperitoneum. The only hemodynamic parameter associated with Trendelenburg was an increase in CVP. Pneumoperitoneum only resulted in an increased MAP. Importantly, cardiac output was not affected either by Trendelenburg position or by pneumoperitoneum. The reader should note that other studies have demonstrated conflicting results in this arena.

Two important clinical scenarios are frequently encountered. First, the patient is found to have profound bradycardia as an initial response to peritoneal insufflation. The abdomen must be swiftly desufflated and anticholinergics administered. If the physiologic response occurs during a closed (Veress) entry technique, rapid desufflation is not immediately possible, as this can only be carried out after primary trocar placement. In this difficult scenario, the surgeon must proceed rapidly without placing the patient at risk from overly aggressive trocar insertion. Attention to safe trocar placement is well worth a few extra seconds of bradycardia.

Second, if an air embolus is suspected, the often cited Durant maneuver [18] is suggested to prevent the "air lock" from sitting in the right ventricular outflow tract. In the original study, animals that were positioned left side down had improved hemodynamics. In this position with the right side up, and furthermore in Trendelenburg, theoretically the air is prevented from entering the pulmonary outflow tract. A central venous catheter may be inserted to aspirate the air. Some authors have since pointed out that these effects have not been reliably reproduced in the human setting, and the position may be cumbersome and impractical in an emergency situation [19]. Nevertheless, the presentation of air embolus is dramatic, especially if Veress needle high pressure insufflation directly into a major vessel is the cause. The patient develops sudden hypoxia, hypercarbia, and cardiovascular collapse.

The overall incidence of subcutaneous emphysema is 0.4–2.3%[20]. Subcutaneous emphysema is typically clinically insignificant and resolves without specific intervention. It may occur with initial preperitoneal Veress needle insufflation. Alternatively, a combination of a snug skin incision and loose fasciotomy around a trocar allows gradual development of ongoing subcutaneous emphysema during the duration of a case. During lower tract laparoscopy, subcutaneous emphysema in the scrotum and penis is not a subtle finding, and should be manually decompressed at the conclusion of the case.

The presence of subcutaneous emphysema underscores the ability of pressurized gas to diffuse between body compartments [20]. Gas may similarly enter the pleural cavity, mediastinum, and pericardial space. Small collections of air in these spaces, without clinical instability, can typically be managed conservatively since CO_2 is readily absorbed.

Complications of patient positioning

The surgeon often relies on gravity and patient positioning for adequate exposure during minimally invasive genitourinary procedures. Patient positioning, and at times prolonged operative times, predisposes the patient to four potentially painful and debilitating problems if precautions are not taken: neuropraxia/neuropathy, rhabdomyolysis, compartment syndrome, and pressure ulcers [15]. Complications in this arena are position and therefore procedure specific. In a large series of urologic laparoscopic procedures compiled from 15 centers and over 1600 cases, the overall incidence of neuropraxia was 2.7%, including rhabdomyolysis in 0.4% [21]. Risk factors included obesity, longer operative times (>5 h), and advanced patient age. In a postoperative patient with oliguria and myalgias, clinical suspicion of rhabdomyolysis is paramount, creatinine kinase should be checked, and the patient should be alkalinized expeditiously.

For upper tract laparoscopy, with the patient flexed in flank position, the following maneuvers are important: use of axillary roll, avoiding excessive flexion, and padding all pressure points. For lower tract surgery, with the patient supine with arms tucked and legs variably positioned per surgeon preference, hands should be in an anatomic position (thumbs up) and sheets to "tuck" arms must not be overly snug around the arm.

End-organ complications

Vascular injury

Bleeding complications account for a substantial portion of laparoscopic complications. For example, intraoperative and postoperative hemorrhage accounted for 40% of all perioperative complications in a recent single institution analysis of urologic laparoscopic procedures from 1997–2006 [22]. The overall incidence of vascular injury during urologic laparoscopy is in the range 0.4–1.7% [1, 2].

The most feared vascular injuries carrying the highest chance of mortality when injured are the great vessels and their immediate branches: aorta, vena cava, and iliac vessels. Mesenteric vascular injury can also be a source of major bleeding. The most common scenario is injury by initial blind Veress needle puncture. This may initially manifest as blood aspirated from the needle. Alternatively, vascular puncture from primary trocar insertion can occur. In either case, possible causes include incorrect angle of insertion and/or uncontrolled axial insertion force. In case of injury, if secondary trocars can be swiftly inserted, holding pressure at the bleeding site with a gauze sponge and laparoscopic grasper (unrolled gauze will fit through a 12-mm trocar) usually gives the surgeon time to assess the situation and, if required, proceed with laparotomy in a controlled fashion [23].

Depending on the bleeding severity and origin, the surgeon must decide whether to use thermal energy, clips, or suture ligatures. With massive hemorrhage, immediate laparotomy is often required. One has precious seconds to determine whether initial laparoscopic attempts at control are feasible or futile. A hand-assist port may be placed as an intermediary to open conversion. If open conversion is required, the laparoscope should be lifted up to the abdominal wall and rapid incision made directly over it. In such an emergency, the incision should be generous for maximal exposure. Compression of the bleeding site allows time for anesthesia to catch up with resuscitation, and allows surgeons with appropriate expertise such as vascular surgery to join the team.

The epigastric vessels are the most commonly injured minor blood vessels during trocar or Veress needle insertion [24], when these are placed laterally off midline (Figure 101.1). Using a Carter–Thomason wound closure device [25], sutures placed above and below the bleeding site are usually sufficient to control the bleeding.

A vascular complication specific to retroperitoneal laparoscopic right-sided nephrectomy is inadvertent ligation of the inferior vena cava (IVC) mistaken for the renal vein [26]. The cause is a lack of orientation to anatomic landmarks. During retroperitoneoscopic surgery, the psoas muscle must be maintained as the "surgical horizon" to maintain orientation. The renal vein must be verified to be heading towards the kidney (90° up, if the psoas horizon is maintained), with expected caliber. Most importantly, the renal vein–IVC junction above and below must be confirmed, as a prerequisite to renal vein ligation. If IVC transection is recognized (Figure 101.2), open vascular repair is suggested.

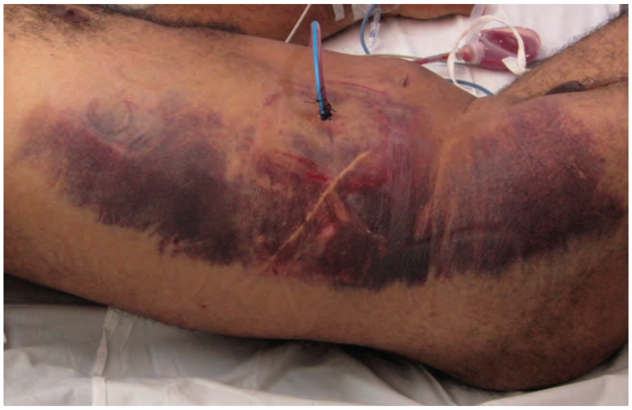

Figure 101.1 Abdominal wall hematoma.

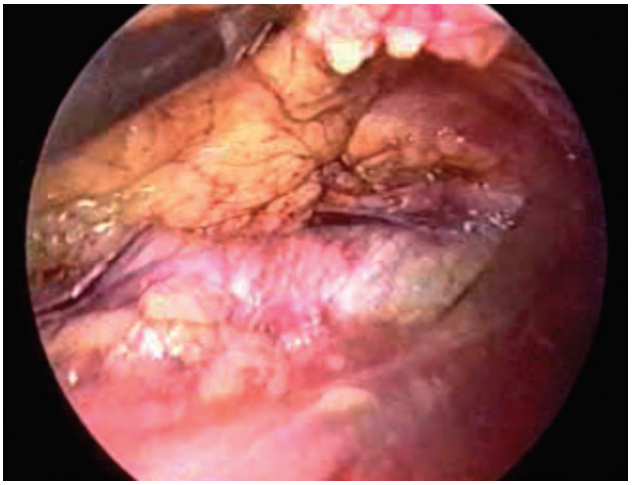

Figure 101.2 Cava transected with vascular stapler, incorrectly identified as a renal vein.

Bleeding is the main complication following partial nephrectomy (1.3–4.3%) [27]. One of the more common causes of intraoperative bleeding is an unclamped, unrecognized accessory renal artery. Great care must be taken both in evaluating preoperative axial imaging and during intraoperative hilar dissection to detect such variations. Delayed bleeding in the setting of hemodynamic stability can be addressed with selective embolization. In cases of hemodynamic instability, re-exploration is warranted. An attempt to ligate bleeding vessels is reasonable, but nephrectomy may be indicated if a single bleeding site is elusive or patient instability does not allow for renorrhaphy. In a large series of laparoscopic partial nephrectomy, reoperation was required in 2% and elective laparoscopic radical nephrectomy was performed in 0.5% [28]. When delayed bleeding manifests as hematuria, vascular fistula should be considered, and can be managed effectively with endovascular embolization.

As with any type of injury, prevention of vascular injury is best A vascular injury "kit" should be prepared with each case (Table 101.2). Dissection should be performed in layers, widely completing more superficial layers before progressing deeper. Vascular injury of varying severity will occur, but poor exposure and "working in a hole" at the outset will severely limit the ability to control an injury. If staplers are used for vascular control, the stapler should be applied a few millimeters distally to provide a stump to grasp in case of catastrophic stapler malfunction [29].

Table 101.2 Bleeding set.

Two laparoscopic needle drivers
Lapra-Ty and/or Weck clips, with appliers
Laparoscopic Satinsky clamp
Bulldog clamps, various sizes
Surgicel absorbable hemostat
Gauze sponge
2-0 Vicryl, SH needle, 10 cm long with Lapra-Ty at the end
2-0 Vicryl, CT-1 needle, 10 cm long with Lapra-Ty at the end
Titanium clip applier, 5 and 10 mm (available in room, unopened)

Bowel injury

The overall incidence of bowel injury in urologic laparoscopy (Figure 101.3) is approximately 0.2–0.7% [2, 3]. Since initial laparoscopic entry is one of the most common times for complications of any sort, a discussion of bowel complications is intimately related to access (see above). Rather than examining procedure-based datasets, a 2001 review examined international claims arising from access injuries from 1980 to 1999 and revealed that small bowel was the most commonly injured individual organ [13]. In this study, which included 594 injuries in 506 patients, claims were compiled both from legal suits made against a physician, and through mandatory device-related incidents reported to the Food and Drug Administration (FDA). When multiple structures were injured, the most frequent combinations involved both a vascular structure and bowel. Of great practical concern was the observation that diagnosis was delayed greater than 24 h for approximately half of all large and small bowel injuries.

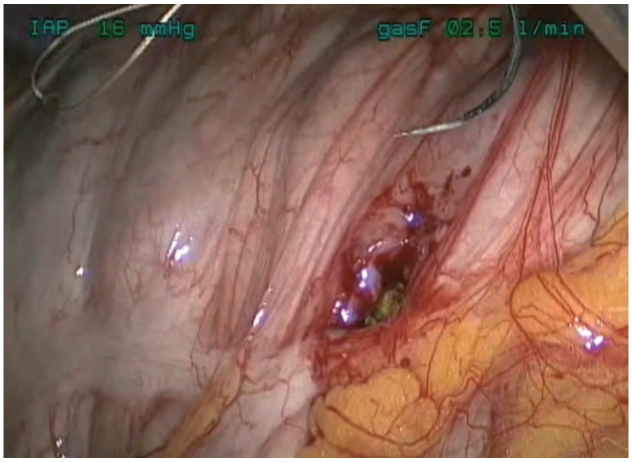

Figure 101.3 Colon injury with primary trocar.

By far the most important take-home message regarding bowel injuries is that the injury may be subtle and early recognition is essential. In the study by Chandler *et al.*, whereas small bowel injury conferred an odds ratio of 1.7 for patient mortality, greater than 24 h delay in diagnosis increased the odds ratio to 3.7 [13]. Even more humbling is that because vascular injuries present so dramatically, delayed bowel injuries are more likely to cause death than major retroperitoneal vessel injury. In another injury-based database based of Medical Device Reports, the mortality rate in cases of delayed bowel injury was 21% [30].

When caused by a Veress needle puncture or trocar tip, laparoscopic repair of large or small bowel with intracorporeal suturing is readily accomplished. For large tears, or when significant adhesions preclude adequate assessment of the full extent of injury, open conversion and repair is recommended.

Trocar site herniation is another potential source of morbidity, occurring in approximately 1% of cases where bladed trocars are used [31] (Figures 101.4 and

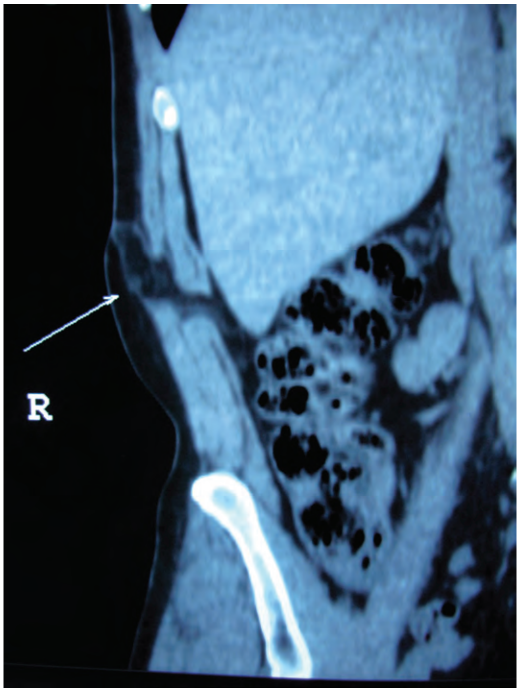

Figure 101.4 Trocar site hernia.

101.5). Standard recommendations for port-site fascial closure include all trocar sites in children and trocar sites greater than 10 mm in adults [32]. The latter has been challenged, since newer dilating (nonbladed) trocars leave a much smaller fascial defect than the diameter of the trocar itself [33]. In our opinion, with modern trocar design there is seldom an indication for bladed disposable trocars as their use invites both vascular injury and postoperative herniation.

Rectal injury, one of the most significant injuries during laparoscopic prostatectomy, occurs in approximately 0.5% of cases [34]. During the dissection, all areas of the rectum in relation to the posterior prostate surface are potentially at risk. Rectal injury can happen at the prostate base (incision too posterior through Denonvilliers' fascia, mid gland (wide neurovascular bundle resection), or apex. Preoperative bowel preparation allows for primary closure alone, since lack of gross fecal contamination may obviate the need for concomitant fecal diversion [35, 36]. Intraoperative diagnosis of even small injuries is best performed by instilling air per rectum with the pelvis filled with irrigant, whereby bubbling confirms rectal injury. Digital rectal examination or transrectal balloon placement may reveal larger injuries. Rectal injury may be further complicated by pelvic abscess (0.1%) or rectourinary fistula (0.1–1%) [37].

Predisposing factors for rectal injury include those that impair tissue integrity and/or obscure tissue planes. These include periprostatic fibrosis from multiple biopsies, prior prostate or rectal surgery, previous radiotherapy, locally advanced tumors, prior hormonal therapy, and prostatic infection. A non-nerve-sparing dissection with a wider dissection plane is also a risk factor, and the surgeon must therefore not be complacent in the belief that non-nerve sparing is an easier operative plane.

Rectal injury (Figure 101.6) can be managed laparoscopically or robotically without open conversion [38]. The defect should be closed primarily in at least two layers of nonabsorbable suture. The integrity of closure can be tested by instilling air in the rectum and watching for bubbles in a fluid-filled pelvis. By tacking the rectum laterally to the levator muscles, the rectal closure is drawn away from the urethrovesical anastomosis, minimizing the chance of fistula. A pedicle of omentum can be brought in over the rectal closure. Diverting colostomy or loop ileostomy should be considered in cases of tension at the rectal closure, massive fecal spillage, prior radiotherapy, and delay in diagnosis. A closed suction drain should be placed, and the patient covered with broad-spectrum antibiotics. A cystourethrogram must be performed prior to catheter removal to exclude urine leak, which may progress to rectourethral fistula if not recognized.

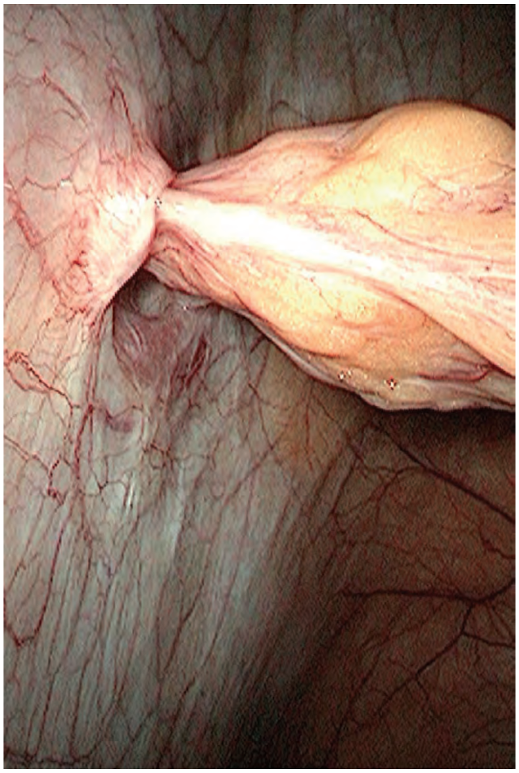

Figure 101.5 Trocar site hernia at time of repair.

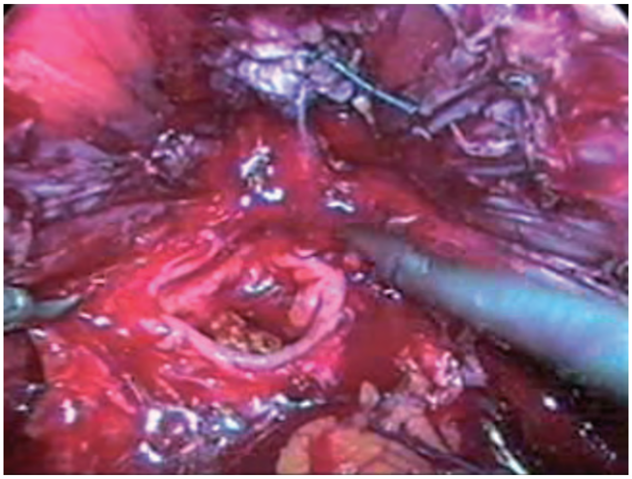

Figure 101.6 Rectal injury during laparoscopic prostatectomy.

Visceral injury

Of solid viscera, the liver and spleen are most at risk during right and left upper tract urologic laparoscopy, respectively. In one of the largest reviews of 2775 urologic laparoscopic procedures, the spleen was injured in 3.2% and the liver in 1.1% of cases [3]. In a meta-analysis broken down by procedure, the spleen was injured in

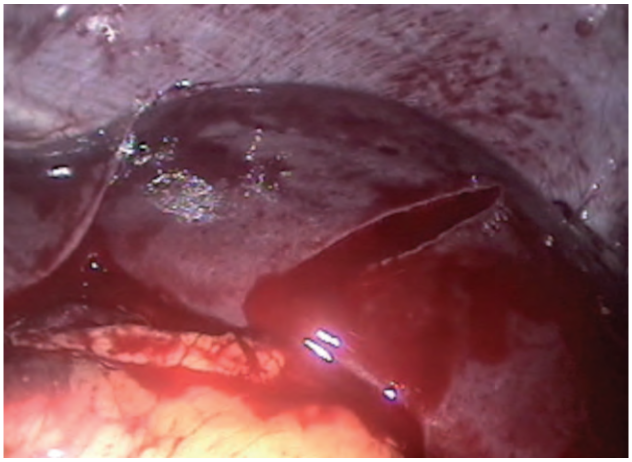

Figure 101.7 Splenic laceration during specimen entrapment.

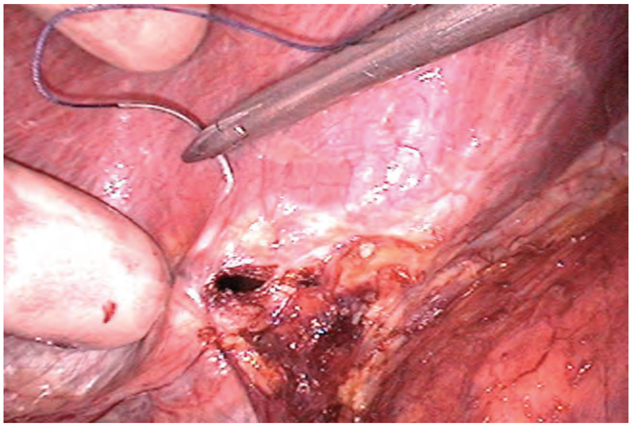

Figure 101.8 Diaphragm injury.

0.5% of radical nephrectomies and 1.3% of donor nephrectomies [39].

Most liver lacerations respond favorably to argon beam coagulation. For both liver and splenic lacerations, hemostatic adjuncts such as Floseal (Baxter, Deerfield, IL, USA) and Surgicel (Ethicon Biosurgery, Somerville, NJ, USA) are also useful. As a last resort, splenectomy should always be considered for severe bleeding or deep lacerations unlikely to resolve with standard maneuvers. The liver and spleen are injured similarly when retracted with an instrument tip rather than a broad surface (Figure 101.7). On the left side, complete mobilization of the spleen from the upper aspect of Gerota's fascia must be accomplished in order to avoid retraction injury.

One commonly encountered scenario is right-sided upper tract (renal or adrenal) surgery in a patient who has previously undergone cholecystectomy and in whom the liver is adherent to the posterior parietal peritoneum over Gerota's fascia. Rather than dissecting the liver directly, the liver should be mobilized with its adherent fascial layers by making an early incision into Gerota's fascia. By entering the retroperitoneum early and reflecting adherent tissue with the liver, injury may be avoided altogether.

The risk of diaphragm injury during urologic laparoscopy was 0.7% in one series [40]. This may occur deliberately as part of planned wide resection of a tumor invading the diaphragm, or inadvertently while dissecting in close proximity to it (Figure 101.8). The first indication that the pleura has been transgressed is a sudden billowing of the diaphragm into the abdominal cavity as the pneumoperitoneum rushes into the chest cavity [41]. Small injuries do not require open conversion to repair. A purse-string suture can be placed laparoscopically around a red rubber catheter exiting through a trocar and immersed in water. As anesthesia expands the lung, the air is evacuated and the suture is rapidly tied down as the catheter is withdrawn [40].

Postoperative complications

Perioperative complications can be classified as either intraoperative or postoperative. In large series, postoperative complications account for approximately half of all complications [1]. The main complications of concern are bleeding (hemorrhage requiring reoperation or transfusion, operative site hematomas), urinoma, and wound complications (infection, hernia). Depending on the procedure, ileus and lymphocele formation are also of concern. The surgeon must be aware that "getting out" safely is as important as gaining access. In this regard, specific maneuvers should be part of standard practice.

Safe laparoscopic exit must include watching all trocar sites for active bleeding after trocar removal. For extirpative procedures requiring an extraction incision, reinsufflating and looking back after fascial closure provides useful information. Lack of bowel entrapment should be confirmed beneath the incision. If significant blood has accumulated during the period of desufflation, an exhaustive search for the bleeding site can obviate the need for re-exploration in the postoperative period. Significant postoperative bleeding presenting with hypotension, anemia, and abdominal distention is a clear sign of hemorrhage, but signs may be more subtle. If a surgical drain has been placed, the rate of filling and quality of fluid are important indicators of bleeding, but absence of blood in the drain does not exclude bleeding. Initial hemoglobin levels may be unchanged before serial measurements uncover anemia.

If surgical exploration is required for postoperative complications, relaparoscopy may be attempted in select cases [42, 43]. If a drain has been placed, it can be used to insufflate the abdomen. Open exploration is fre-

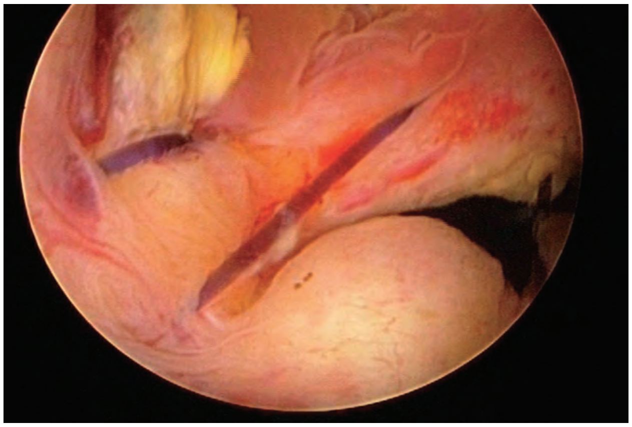

Figure 101.9 Urine leak at urethrovesical anastomosis, anastomotic separation on cystoscopic view.

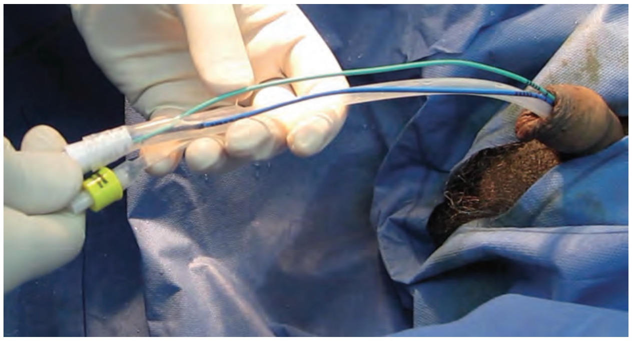

Figure 101.10 Bilateral externalized ureteral catheters alongside Foley catheter for urethrovesical anastomotic leak.

quently required, but generalizations in this regard are difficult. For instance, re-exploration for bleeding following partial nephrectomy in a stable patient may be ideally suited to the laparoscopic approach as exposure of the renorrhaphy bed will be feasible. In contrast, bleeding following cystectomy and neobladder will be difficult laparoscopically as the urinary diversion and mesentery are now space-occupying structures obscuring view, and open exploration is warranted.

Urine leak in the postoperative period is pertinent after laparoscopy, pyeloplasty, and prostatectomy. Management of urine leak after pyeloplasty is initially conservative, as the majority will resolve following a period of encouraging maximal drainage (ureteral stent, Foley catheter, perirenal drain). A persistent vesicourethral anastomotic leak after laparoscopic radical prostatectomy is an uncommon complication with an unclear incidence (Figure 101.9). In one series, the incidence of leak requiring reoperation was 0.9–2.5% [42]. Most urinary leaks occur in the immediate postoperative period and are usually self-limiting with prolonged bladder drainage. Rarely, the surgeon encounters an anastomotic leak that does not resolve in the first 2 weeks.

Several conservative interventions are available for prolonged vesicourethral anastomotic leaks (Figure 101.10). These include prolonged retropubic and bladder drainage, passive rather than active drainage, advancing the drain away from the leak, bladder catheter traction, and bladder catheter needle-vented suction [44]. Particularly when the ureteral orifices are near the anastomosis, invasive techniques should be performed, including placing internalized or externalized ureteral stents. In case of ileus, abdominal pain, and/or urinoma, cystoscopy can provide information as to the degree of anastomotic separation. Laparoscopic re-exploration can be performed, the intra-abdominal urine evacuated, and the anastomosis either redone entirely or additional sutures placed.

Miscellaneous complications

Obturator nerve

The incidence of obturator nerve injury reported for open prostatectomy is 0.1–1%, and for minimally invasive prostatectomy 0.3% [45]. Given that the obturator nerve is fixed at either end, nerve mobilization to gain additional length is not feasible. As such, in the case of nerve loss, an interposition nerve graft may be necessary. If possible, an end-to-end reanastomosis with fine suture is ideal.

To avoid obturator nerve injury, a thorough understanding of normal anatomy is crucial, as this structure is one of the most reproducible, and its position scarcely varies in relation to bony landmarks. During lymphadenectomy, the lymph node packet should first be mobilized distally and reflected completely from the anterior surface of the nerve. When ligating the packet, it should be retracted medially, such that the full nerve is in view. Placing a clip parallel and medial to the course of the nerve will prevent inadvertent nerve injury.

Ureteral injury

Ureteral injury is uncommon during laparoscopic upper tract surgery as its course is familiar to urologists. However, it is occasionally subject to injury during the learning curve of laparoscopic and robotic prostatectomy where its proximity to the seminal vesicle and bladder neck (ureteral orifices) are unexpected and unfamiliar. Ureteral injury was initially reported during the Montsouris posterior approach to the seminal vesical dissection, where the ureter was mistaken for the vas deferens [46]. In general, this is from errant dissection too far laterally. Double checking before ligating or

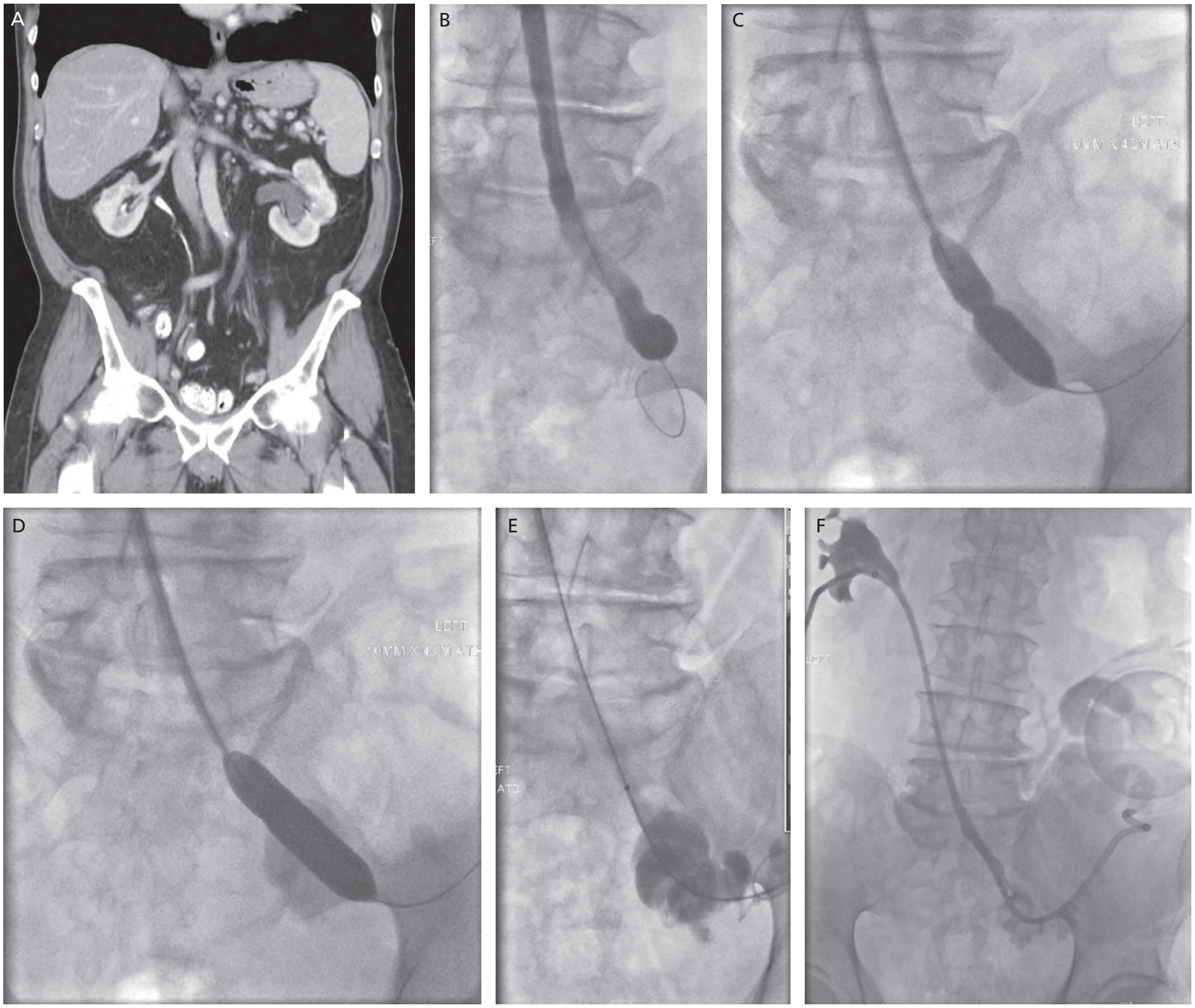

Figure 101.11 Left ureteroenteric anastomotic stricture after robotic cystectomy. (A) Left hydroureteronephrosis on CT scan, (B) cut-off point on antegrade nephrostogram, (C, D) balloon dilation, (E) contrast flow into ileal loop, (F) nephroureteral stent in place.

dividing a tubular structure will prevent ureteral injury in this context. The other area of potential ureteral injury is the trigone. Care must be taken both during the posterior bladder neck dissection and during the anastomosis to identify the ureteral orifice. The incidence of ureteral injury during laparoscopic prostatectomy is approximately 0.8% [36, 47].

When ureteral injury is diagnosed intraoperatively, management depends on the injury type. Focal contusion without thermal energy may be managed conservatively with a ureteral stent alone. Suture repair and stenting of partial lacerations are appropriate. For complete transection, end-to-end anastomosis may be possible, but reimplantation is often a safer solution. When detection is delayed, repair is dictated by the location and extent of the injury, with the majority of injuries below the iliac vessels being managed with reimplantation. Percutaneous antegrade balloon dilatation may be suitable for delayed ureteric anastomotic stricture (Figure 101.11).

Conclusions

Comprehensive preoperative planning and surgeon preparation can minimize or prevent complications from minimally invasive surgery. Particular care must be exercised during the learning curve, as multiple series have demonstrated that complications decrease with experience. The impact and sequelae of complications when they do occur can be minimized by rapid recognition and appropriate treatment. Humility is important; the first step in recognizing complications is being open to their occurrence. With this broad overview, the reader should be better placed to avoid complications, equipped to swiftly diagnose them, and more able to intervene should they occur.

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CHAPTER 102

LESS and NOTES: History and Introduction

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Introduction

Surgeons have traditionally used large incisions on the abdominal wall to access the organs within, believing in "big cut, big surgeon." While this may have been true in the days of poor illumination and instrumentation, rapid improvements in these has meant that safer surgery can be done with less exposure. Cosmetic appearances became important to the patient once the basic safety of surgeries was established. This culminated in the development of laparoscopic surgery, where an endoscope and instruments passed through multiple small incisions are used to operate on organs within the abdominal cavity. Laparoscopy has progressed to a point where it is accepted as a gold standard for many commonly performed abdominal surgeries.

Urologists have been at the forefront of minimally invasive surgery from the beginning. They have been the pioneers in using natural orifices to operate on genitourinary organs. Transurethral resection of the prostate (TURP) remains the gold standard in the operative treatment of benign prostatic hyperplasia (BPH). The pioneering efforts of Clayman and Gaur heralded the entry of urologists into laparoscopy and retroperitoneoscopy [1, 2]. It is now over 20 years since Clayman performed the first laparoscopic nephrectomy, and laparoscopy is now routinely performed for many benign and malignant conditions of the genitourinary tract. It is now common to perform even complex reconstructive surgeries in a minimally invasive fashion. The trend towards minimally invasive surgery has progressed to a point where it is possible to operate on the patient without any external incision or by hiding the incision so that no scar may be visible.

Natural orifice translumenal endoscopic surgery

The first description of the procedure known as NOTES (natural orifice translumenal endoscopic surgery) is credited to Kalloo *et al*. in 2000, and published in 2004; they demonstrated the feasibility and safety of a per oral transgastric endoscopic approach to the peritoneal cavity with long-term survival in a porcine model [3]. Meanwhile, Gettman *et al*. in 2002 published the first description of a natural orifice surgery in a series of transvaginal porcine nephrectomies [4]. Rao *et al*. reported the first human case of NOTES in 2004 with a transgastric appendectomy [5]. It was becoming clear that this was an emerging field of minimally invasive surgery, and regulation of procedures performed and guidance to physicians intending to perform these procedures was vital to the growth of these surgeries.

In July 2005, some of the leaders in this field who represented the American Society of Gastrointestinal Endoscopy (ASGE) and the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) met, and their deliberations were published as a White Paper of the ASGE/SAGES working group on NOTES [6]. The paper discussed the possible technical barriers to NOTES; recommended the involvement of a surgeon and endoscopist in any team carrying out these

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procedures, and sharing of complications with other groups doing similar procedures via a central registry; and emphasized the need for Institutional Review Board (IRB) approval before using this approach in humans. The working group was named the Natural Orifice Surgery Consortium for Assessment and Research (NOSCAR). NOSCAR has met four times since this initial meeting. It continues to set the standards for the development of the specialty, documents new techniques, and maintains a database of the procedures that have been done.

Pure NOTES

"Pure" NOTES describes the procedure performed through natural orifices only: trangastric or transesophageal (through the oral cavity), transvaginal, transcolonic or transvesical. All these routes have been reported in animal models. Most human cases of pure NOTES have been transgastric or transvaginal.

The transgastric route is the commonest route described for NOTES procedures so far. Gastrointestinal endoscopists are the most familiar with this route and they have driven the innovation in this field. The primary difficulties associated with this route appear to be the lack of a device for secure closure of the stomach [7], difficult orientation after retroflexing the scope in the peritoneal cavity, particularly for a cholecystectomy or upper abdominal procedures, as well as inadequate illumination of the capacious peritoneal cavity.

The transesophageal route also has been used to access the mediastinum in an animal model and various procedures can be performed, including pleural biopsy and cardiomyotomy [8].

The transvaginal route has been used for NOTES with some success. It is the most commonly used route in urologic applications with a fair number of reports of procedures performed in animals by this route [4, 9]. This route was also used in the first human urologic experiences of pure NOTES, as well as hybrid techniques, for performing nephrectomies [10, 11]. Closure of the vagina is fairly easy and being a capacious organ, it is possible to use rigid laparoscopic instruments which surgeons are more familiar with. Using this route obviously excludes the male population. Some gynecologists remain concerned about adhesions in the pelvis and subsequent infertility after these procedures. There are also concerns about spread of endometriosis and that this also may lead to dyspareunia in the postoperative period [12].

Unlike the transvaginal route, the transcolonic route is not gender specific. A NOTES sigmoid colectomy with primary anastomosis has been reported using this route in a human cadaver model [13]. The main problems with this route are contamination of the peritoneal cavity with colonic contents and unreliable closure of the colon after the procedure.

The transvesical route is attractive to urologists who are familiar with the organ. The bladder can be closed with endoscopic suturing techniques and a small rent can also heal with just catheterization. Only experimental surgeries have been performed by this route so far [14].

Multiportal NOTES

Rendezvous NOTES is an approach where more than one portal of entry is used to avail of triangulation or better vision or safety in doing the procedure. In these techniques, which remain experimental, transgastric/transcolonic routes have been used for cadaveric small bowel resection, and the transgastric/transvaginal approach has been used for porcine nephrectomies [15–17].

Hybrid NOTES is the use of any natural orifice together with one or more transabdominal laparoscopic ports. The lack of effective clipping/stapling devices for use through flexible endoscopes make it much easier to carry out these tasks through the additional laparoscopic port. Also, use of an additional transumbilical access, albeit a needlescopic port for visualization of entry into the peritoneal cavity via the viscus, makes the procedure much safer. As will be seen during the discussion on LESS below, the cosmetic sequelae of a port in the umbilicus are negligible. This has been the commonest type of procedure done in humans [18, 19] and has been used for a variety of procedures, including radical nephrectomy and cholecystectomy [11, 20].

Hybrid NOTES should be seen as a stepping stone in developing the technique of pure NOTES. It helps the surgeons to gain experience in the use of and the view with flexible endoscopes, while ensuring safety for the patient undergoing these new procedures.

Robotic NOTES is an exciting new development. There have been reports of using the da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA) in animals to perform various reconstructive and ablative urologic procedures [21, 22] Most of these reports use hybrid NOTES as the cumbersome nature of current robotic systems mean that otherwise the arms would clash. The most interesting development in this area is the use of flexible robotics and mini-robots to carry out different procedures. Flexible robotics has been used clinically with success to perform renoscopy to fragment renal calculi [23–25]. The NOSCAR working group in 2008 identified access, navigation, maneuverability, and stability to withstand instrument forces as the essential requirements for a successful NOTES platform. There is no single NOTES platform that can deliver all of these. Robotics might have the answer. A multichannel flexible robotic device has been used in a cadaver study by the transgastric route [26]. *In vivo* mini-robots have been described experimentally that can be introduced into the peritoneal cavity via a natural orifice to explore the peritoneum and perform surgeries [27, 28].

Difficulties

There are various problems associated with NOTES. The perforation of a "normal" viscus to get at an abnormal organ seems to contravene the natural process of commonsense, besides being hazardous, should the closure be insecure, or leak post procedure. Regarding the transvaginal route, this excludes half the population, may not be appropriate in the younger population who have not completed child bearing, and may even be difficult and unethical in sexually inactive young patients.

The instruments being used for NOTES today are the standard off–the-shelf double-channel endoscopes and also sometimes rigid laparoscopic instruments for hybrid NOTES. The passage of two instruments down the channel of the endoscope considerably limits their use [5]. It is difficult to hold and retract normal organs with the flimsy endoscopic instruments, let alone organs inflamed and enlarged by disease. Use of a flexible endoscope to pass these instruments has the disadvantage of excessive mobility, making these procedures more cumbersome as the endoscope easily gets lost in the insufflated and capacious abdominal cavity. Also, it is difficult to achieve triangulation as the channels are parallel.

NOTES is an exciting new technology but has a long way to go before it can be used routinely in clinical practice. Development of newer materials and instruments will likely improve the practice of these types of surgeries. Overcoming the remaining obstacles will require close cooperation between engineers and surgeons. Variations like hybrid NOTES and newer technologies like LESS surgery are stepping stones towards the fully fledged utilization of NOTES in clinical practice.

Laparoendoscopic single-site surgery

The development of new multichannel access devices and articulating instruments has lead to another exciting new advance in laparoscopic surgery; laparoendoscopic single-site surgery (LESS) [29]. The first cases of single-port access in urology were reported by Rane and Rao using a new access device, the R-Port™ (Advanced Surgical Concepts, Wicklow, Ireland). The cases, which included the first successful single-port nephrectomy and ureterolithotomy, were performed in May 2007 [30, 31]. At around the same time, Cadeddu *et al*. were working on a similar technique, using three separate trocars through a single incision in the umbilicus to do nephrectomies. They reported this procedure in an animal model as well as in the first human clinical cases [32]. Desai *et al*. used the R-Port for reconstructive as well as ablative procedures through the umbilicus in clinical cases, giving almost a scarless appearance post surgery [33]. The umbilicus is a ubiquitous cicatrix from birth and can be used to conceal the access into the abdominal cavity.

Single-port laparoscopy is not new. It has been around for more than 30 years. Gynecologists have been performing tubal ligation with a single puncture laparoscope since it was introduced in the late 1970s [34, 35]. This technique, however, is only applicable to the most basic surgery, especially gynecologic surgery where the uterus can be manipulated from below, obviating the need for retraction. These early instruments had offset eyepieces with a straight operating channel through which an instrument (usually an applicator for the ring to occlude the tubes) could be passed [36, 37]. The advantages of using a second instrument with triangulation were noted at the time [38]. The use of multiple trocars rapidly gained popularity because of the disadvantages of using a single puncture.

As conventional laparoscopy became popular even for complex reconstructive procedures in surgery and urology, it was usually carried out through –three to six ports. However, the increasing numbers of ports led to reduced cosmesis, more pain, and increased risk of complications due to port-site infections and hernias [39, 40], and reducing these complications was an incentive to develop techniques that employed fewer ports. While NOTES represents the ultimate in minimally invasive surgery by avoiding abdominal incisions altogether, single-port/single-site surgery is a step towards that goal [41]. Also, while there were isolated reports of purely transumbilical surgery, the lack of adequate access devices and instrumentation prevented the spread of the technique at the time [42].

Terminology

As more and more centers started doing this type of surgery, papers were published using different nomenclatures for the surgery [31, 32, 43–48] (Table 102.1). There was a need to unify the nomenclature under a single umbrella similar to NOTES so that it would be easier to document new developments and guide this emerging technique of minimally invasive surgery. A multidisciplinary consortium of surgeons, named LESSCAR (Laparo-Endoscopic Single Site Surgery Consortium for Assessment and Research), was brought together by Gill at Cleveland in July 2008. It suggested the term LESS for all procedures using a single site or single port for access. The consortium also suggested a standardization for reporting these surgeries, "To clearly

Table 102.1 Acronyms used to describe single-port/single-site surgery.

SPA: single port access
SILS: single incision laparoscopic surgery
OPUS: one port umbilical surgery
E-NOTES: embryonic natural orifice transluminal endoscopic surgery (as the umbilicus is an embryonic structure)
SIMPLE: single incision multiport laparoendoscopic surgery
SPS: single port surgery
VSUS: visibly scarless urologic surgery
SIL: single incision laparoscopy
SPL: single port laparoscopy
R-NOTES: robot-assisted natural orifice transumbilical endoscopic surgery
U-NOTES: umbilical natural orifice transluminal endoscopic surgery
LESS: laparoendoscopic single-site surgery
NOTUS: natural orifice transumbilical surgery
TUES: transumbilical endoscopic surgery
TULA: transumbilical laparoscopic surgery
SLaPP: single laparoscopic port procedure

and fully convey all procedural details, a ‘mandatory descriptive second line’ should be required in all scientific publications, which succinctly provides all relevant information at the very outset, such as: single incision length and location [abdominal (umbilical or extra-umbilical), thoracic, or pelvic]; approach (transperitoneal, retroperitoneal, percutaneous intraluminal, transluminal); number/type of ports used; laparoscopic, endoscopic or robotic; type of laparoscope used (straight or flexible); type of instruments used (straight, curved, bent, articulating, or flexible); and whether any ancillary 2-mm needlescopic instrumentation is employed” [29]. Similar to NOSCAR, the mandate for LESSCAR included creating a multidisciplinary group, soliciting funding, establishing a registry and database of procedures performed, coordinating LESS research, and collaborating with other established professional organizations to facilitate LESS presentations at their meetings. The criteria for LESSCAR membership were kept inclusive so as to allow maximum participation, while insisting on IRB approval to carry out LESS clinical research [29].

Development of LESS

The main problems with performing LESS surgery are a loss of triangulation, clashing of instruments and the endoscope which are close together, and a lack of maneuverability. This new technique of surgery could progress only by circumventing these issues. LESS has mainly been driven by the availability of new technologies, which have enabled surgeons to overcome these difficulties.

Table 102.2 Solutions to problems in single-site surgery.

Problem	Solution
Damage to light fiber of conventional laparoscope	Use of optic with coaxial light fiber (e.g. EndoEye™)
Clashing of telescope with instruments	Use of deflectable tip telescope
Loss of triangulation	Use of articulating or prebent instruments
Clashing of trocars within the abdominal cavity	Use of short trocars
Multiple sheath incisions leaving Swiss cheese defects	Use of access device with single incision (Triport, Quadport, SILS port, XCone)

The early experience with LESS can be attributed to the development of new access devices (the R-Port™ and the Uni-X™) and new articulating instruments (Real Hand™ (Novare Surgical Systems, Cupertino, CA, USA). These new access devices permit the surgeon to insert more than one instrument (and an optic) through the same port [30, 31, 49, 50]. The articulating instruments can be used through conventional straight trocars, which were passed through a single site (usually the umbilicus) to give a sense of triangulation (see below) [32, 47]. When short trocars are used in this technique, they reduce (but do not completely prevent) the clashing of the instruments close to the abdominal wall.

As with most new surgical techniques, the early development of LESS surgery was mainly about overcoming the various problems associated with a new approach. Each problem had to be identified and a solution sought (Table 102.2). Fortunately, technology in optics and instrumentation has just about reached the point where this is possible. A few novel ideas like prebent instruments were developed with this type of surgery. Prebent Instruments cannot be passed through conventional trocars which are straight and rigid [30], but they can be passed through some of the newer generation access devices like the Triport and Quadport, which have a very low profile inside the abdominal wall. Articulating instruments were originally developed to mimic the freedom of movement afforded by the robotic wrist of the da Vinci surgical robot and were to be used through the conventional straight trocars used by the robotic arms. They were ideally suited to be used by the first surgeons doing single-site surgery through the umbilicus using conventional straight trocars, giving a sense of triangulation. Triangulation is one of the fundamental concepts of laparoscopic surgery, as it permits traction on tissues to facilitate dissection along normal anatomic planes. Articulating instrumentation allows for triangulation to occur intracorporeally despite the trocars being adjacent to one another through the same skin incision [32]. Instruments may cross at times. Also, as initially demonstrated by Raman *et al.*, the use of a deflectable tip laparoscope is uniquely suited to this type of surgery [47]. It must, however, be noted that use of this type of laparoscope does have a learning curve for the assistant holding the scope.

In addition to the use of the new devices, single-site surgery was also carried out using access devices that were already available, along with regular laparoscopic hand instruments [51]. Some of the earlier hand-access devices like the Gelport are suited to single-incision surgery as they allow multiple instruments to be passed through them. They have the additional benefit of allowing the specimen to be removed easily after ablative surgeries.

LESS and NOTES:the present and future

Since the introduction of single-site surgery in 2007, it has rapidly gained popularity with surgeons as well as manufacturers. Several hundred cases have been performed with a significant number being reported in peer-reviewed journals [52, 53]. Much new equipment has been developed for this in a very short period of time. This is in stark comparison to NOTES for which clinical data have only recently been published in spite of the availability of the procedure for about 10 years. The reasons for this are obvious.

With LESS, the surgeon has a more conventional view of the field of surgery as compared with a transvaginal or transgastric view. The equipment used for LESS is familiar to urologists already doing laparoscopic surgery. Most importantly, it is easy to convert LESS to conventional laparoscopy by adding a few trocars. This ensures the safety of the patient during the surgeon's early experience [54]. Most of the reported LESS procedures seem to have equivalent efficacy to conventional laparoscopy, including operative times, blood loss, and length of hospital stay. What remains to be seen with time and increasing numbers of cases, which will lend statistical validity to the comparisons, is whether LESS offers enough advantages (cosmetic or otherwise) to coexist with conventional laparoscopy. There is a significantly longer learning curve with LESS than for conventional laparoscopy and the benefits need to outweigh the increased difficulties of learning and performing these techniques. Comparisons are already being made in surgeries such as donor nephrectomies [55, 56]. This is where LESS can make a significant contribution by expanding the donor pool. It needs to be determined if this is a meaningful and lasting technique or a stepping stone towards a truly scarless intervention [57].

With NOTES, surgeons are not used to the endoscopic views and in urology, it remains a research interest, although a few experienced surgeons have performed the occasional clinical case [10, 11]. Although undoubtedly a very attractive concept, for NOTES to be used routinely in urology, instrumentation and optics need to improve to the point where a good outcome can be assured. NOTES is one of the most exciting new clinical modalities and considerable advances are bound to be seen over the next few years in this field.

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CHAPTER 103

NOTES: Instruments, Platforms, and Endoscopes

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Introduction

Natural orifice extraction of internal organs without disfiguring cutaneous incisions can be dated back approximately 2500 years with the embalming process of cadavers by the ancient Egyptians in which the brain was removed transnasally, a process described by the Ancient Greek author Herodotus [1]. It was not until the early 20th century that transnasal transphenoidal surgery was used for therapeutic procedures [2]. The initial transrectal procedures and first documented endoscopic procedures were use of the transrectal speculum using natural light in the fifth century BC by the Kos school of Hippocrates. A variety of other endoscopic specula were used in the ancient and medieval periods for the vagina, nares, and ear, using natural light [3]. According to a review by Baskett, the earliest use of a natural orifice for extirpation of internal organs in living humans was likely by the ancient Greeks [4]. Themison of Athens is credited with removal of the prolapsed uterus in women who subsequently survived the procedure in the first century BC. The first documented description in modern times was by Berengario da Carpi who performed the vaginal removal of a prolapsed uterus in 1517. Sauter of Baden reported the first planned vaginal hysterectomy for cervical cancer and gave the first clear description of entry into the abdominal cavity, demonstrated by prolapse of bowels through the incision in 1822. This patient survived for 6 months [4]. This latter case demonstrates the initial report of peritoneal access through a natural orifice incision occurred nearly two centuries ago, albeit as a complication.

Other natural orifices were also used earlier in the modern era for access to internal organs in living patients. Bezzini described the first cystoscope in 1805 but was apparently unable to use it clinically due to poor visualization and the heat of the instrument [3]. With subsequent developments, therapeutic procedures of the bladder became possible later in the 19th century. The ureter and renal pelvis were first accessed transurethrally by Hugh Hampton Young in 1912 [5]. Although there were descriptions of rigid rod scopes being used in the 1870s, effective gastrointestinal endoscopy, whether to access the stomach and duodenum perorally or to visualize the entire colon with colonoscopy, depended on the development of fiberoptic flexible endoscopes, the first of which was successfully used in 1957 [3].

The development of laparoscopy represented a means of performing intra-abdominal procedures with small transcutaneous incisions and use of scopes rather than the relatively large incisions that were traditionally required. Laparoscopy, as a concept, was first introduced by Kelling in the early 1900s with insertion of a rigid Nitze–Leiter cystoscope into the canine abdomen to perform peritoneoscopy [6] However, laparoscopy was limited mostly to gynecologic surgeons who used the modality typically for diagnostic peritoneoscopy and simple procedures such as elective sterilizations.

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Acceptance of laparoscopy for more complicated therapeutic procedures did not occur until the 1980s with the adaptation of laparoscopy for cholecystectomy coupled with improvements in video capabilities [3]. In urology, the new modality was used to perform a laparoscopic nephrectomy in 1991 by Clayman *et al*. [7] and was subsequently adapted to a wide variety of urologic procedures.

Intentional use of natural orifices as an access point for abdominal, retroperitoneal, pelvic, and even thoracic laparoendoscopic surgery is a new phenomenon. Gettman *et al*. described the initial laboratory work with transvaginal nephrectomy in the porcine model in 2002 [8]. However, an explosion of interest in natural orifice surgery followed from the work of Kalloo's group who described a variety of transgastric surgical procedures in the porcine model [9] and a video by Reddy and Rao of a completely transgastric appendectomy in the clinical setting [10], both in 2004. Natural orifice translumenal endoscopic surgery (NOTES), as these approaches have been collectively termed, thus represents a convergence of laparoscopy and endoscopy to perform surgery that would traditionally have required access by cutaneous incisions using endoscopic equipment that is introduced through natural orifices. As such, it is a promising development in minimally invasive surgery, which could represent a new paradigm in surgical management.

The term NOTES was adopted by a consortium of gastroenterologists and general surgeons called NOSCAR (Natural Orifice Surgery Coalition for Assessment and Research) in 2005 [11] and has gained acceptance in other specialties including urology [12]. While an obvious advantage of NOTES over other surgical procedures is improved cosmesis, practical benefits of NOTES could include potential for reduced postoperative pain, anesthesia requirements, and adhesions, and risk of infections and incisional hernias, as well as possible advantages in morbidly obese individuals [13, 14]. A number of challenges remain, including safe access and closure, especially in orifices with a high bacterial load.

The concept of NOTES clearly stimulated an interest in "scarless surgery," while also challenging the traditional paradigm of triangulation of instruments. Coupled with the recognition of limitations of existing equipment and platforms and other concerns of natural orifice surgery, much of this enthusiasm was then channeled into the development of laparoendoscopic single-site surgery (LESS). The latter is now becoming increasingly popular for clinical applications and can be virtually scarless when performed at the umbilicus. Alternatively, two intermediate approaches that straddle the two concepts are "hybrid NOTES" and "hybrid LESS," which involve a combination of natural orifice and transcutaneous approaches. The distinction between these terms primarily reflects the degree to which the natural orifice is used to perform the procedure, although a hybrid NOTES procedure can involve more than one cutaneous incision, while a hybrid LESS procedure involves only a single incision [12]. Indeed, with exceptions, most of the clinically described NOTES procedures to date have involved hybrid procedures.

This chapter will describe current applications of NOTES both clinically and in the laboratory, and will review some of the major challenges of translumenal approaches. Conventional and novel equipment and platforms that have been used to overcome these obstacles will then be discussed. Due to rapid innovation in the field, we would caution that any attempt to exhaustively detail the equipment used in these new approaches will rapidly become obsolete. Therefore, general concepts are emphasized with the described equipment being illustrative of approaches that have been used to date by various researchers and not necessarily an indication of commercial or practical feasibility in the clinical setting.

Overview of natural orifices and NOTES procedures

The natural orifices that could theoretically be used to access the abdomen and retroperitoneum include the vagina, oral cavity, nares, urethra, and rectum. However, the terminology used to describe the NOTES procedure emphasizes the organ that is incised, as the orifice used is typically implied. For example, the vast majority (if not all) transgastric procedures to date access the stomach transorally rather than through the nares. The NOTES procedures described below are categorized by NOTES access.

Vagina (transvaginal)

As already described, a vaginal approach has long been used for extirpative surgery with documented peritoneal access almost two centuries ago. Given the ease of access, this orifice is perhaps the most promising for insertion of endoscopic or even laparoscopic cameras and instrumentation. As noted, the initial translumenal endoscopic procedure was the pure NOTES nephrectomy in the porcine model by Gettman *et al*. in 2002 in a study that predated the term NOTES (8). In actual clinical practice, the vagina has been the most utilized NOTES access to date for abdominal and pelvic procedures. The first transvaginal NOTES procedures in humans were likely the transvaginal NOTES cholecystectomy reported by Zorron *et al*. in 2007 [15] and the transvaginal NOTES appendectomy reported in 2008 by Palanivelu *et al*. [16].

The first clinical procedure in urology that qualifies as NOTES in the purest sense was the transvaginal radical nephrectomy performed in 2009 by Kaouk *et al*. [17]. They reported that all operative steps were performed transvaginally, including removal of the intact kidney transvaginally without assistance of additional ports. For this procedure, they used a vaginally placed GelPort™ device (Applied Medical, Rancho Santa Margarita, CA, USA). Leading up to this important accomplishment were several reports of hybrid transvaginal NOTES nephrectomies. In 2007, Branco *et al*. described a hybrid nephrectomy with two 5-mm abdominal trocars and the scope through the vagina [18]. Sotelo *et al*. then reported in 2008 a hybrid transvaginal NOTES nephrectomy using only an umbilical access transabdominally, consistent with the goal of scarless surgery [19]. A hybrid transvaginal donor nephrectomy was also described in the press by Allaf *et al*., also in 2009, but has not been formally published as of this writing, and involved three abdominal incisions one of which was at the umbilicus [20]. Transvaginal NOTES retroperitoneal nephrectomy has also been described in the porcine model [21]. Clearly a major limitation of this approach is its applicability to only half the population as it is limited to women.

Oral cavity/stomach (transgastric)

As noted above, Kalloo *et al*. described the initial intentional use of the stomach to access the peritoneum and perform surgeries in the porcine model [9], which was followed soon thereafter by Reddy and Rao's therapeutic transgastric NOTES appendectomy video shown at a conference in 2004 (although the work remains unpublished) [10]. Marks *et al*. described a bedside transgastric PEG "rescue" in an intensive care patient with a dislodged gastrotomy tube in 2007 [14] A prospective clinical study of transgastric diagnostic peritoneoscopy in ten patients was reported to have favorable results [22]. There have now been a wide variety of transgastric procedures performed to date in the laboratory. There is also a growing experience with urologic NOTES procedures using transgastric access. Transgastric NOTES renal surgery in the porcine model includes combined transgastric and transvaginal nephrectomy by our group [13] (Figures 103.1 and 103.2); combined transgastric and transvesical nephrectomy by Lima *et al*. [23]; and transgastric partial nephrectomy by Boylu *et al*. [24]. Our group also evaluated the bladder by performing transgastric NOTES partial cystectomy [25]. Despite significant interest in this approach, there remain significant questions of safe access and closure, especially given difficulties in sterilizing the stomach and potential for gastric leakage.

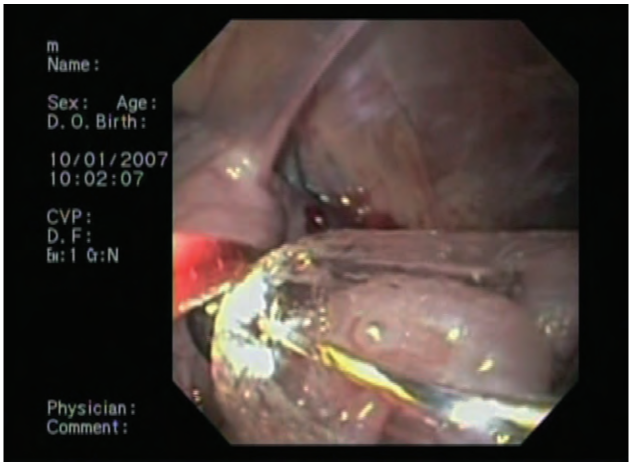

Figure 103.1 Balloon dilation of colpotomy. View from a transgastric pediatric endoscope.

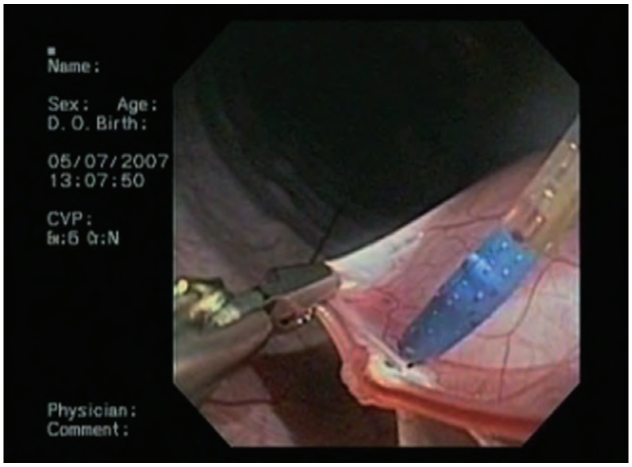

Figure 103.2 Dissection of perirenal tissue using a needle knife device through the gastroscope in combined transgastric and transvaginal NOTES nephrectomy.

Urethra/bladder (transurethral/transvesical)

A significant advantage of a transvesical access is the relative sterility of urine [26], but the relatively small size of the orifice has limited investigations. To date there has been to our knowledge only a single clinical report of intended transvesical peritoneoscopy. This report used a flexible ureteroscope through a vesicotomy that was first balloon dilated [26]. In a human cadaveric model, Humphreys *et al*. described a transurethral NOTES radical prostatectomy [27]. In the porcine model, Lima *et al*. used transvesical NOTES approaches for peritoneoscopy, liver biopsy, and thoracoscopy using a ureteroscope [28, 29]. This group also reported combined transvesical and transgastric NOTES to perform cholecystectomy [30] and nephrectomy [23], although the latter was without specimen extraction. Our group

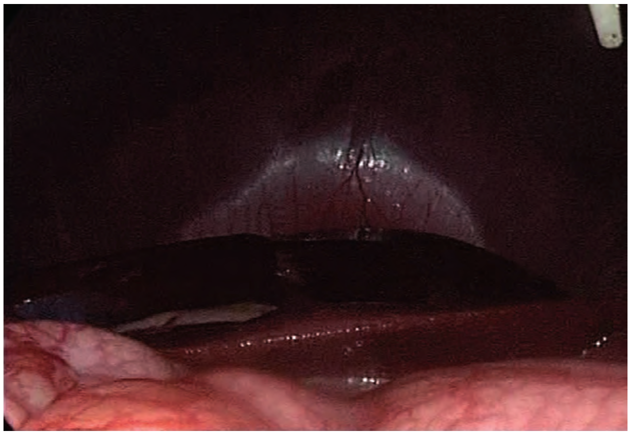

Figure 103.3 Transvesical visualization of liver and diaphragm using a rigid cystoscope in a 20-kg pig.

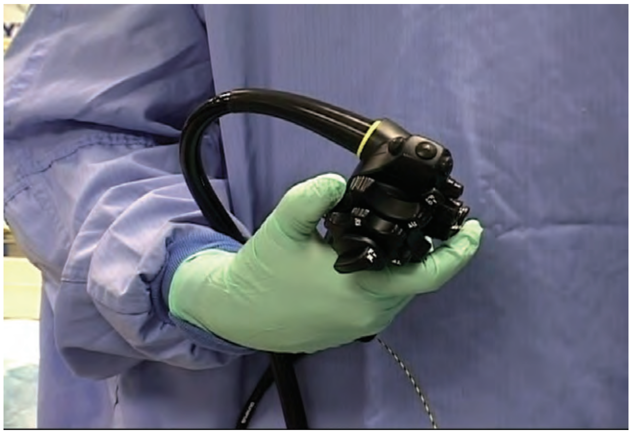

Figure 103.4 Pediatric gastroscope used for transvesical, transvaginal and transgastric NOTES.

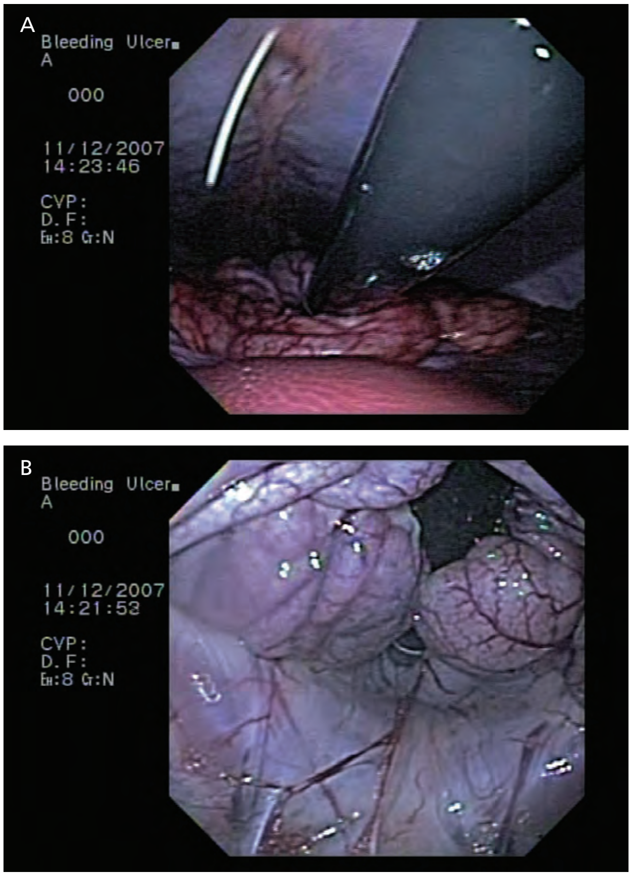

Figure 103.5 (A, B) Transvesical pediatric gastroscope in retroflexion, permitting visualization of the liver, bowel, and pelvis.

has also performed transvesical peritoneoscopy using both the dual channel rigid cystoscope, including simple bowel manipulation [31], and the pediatric gastroscope (Figures 103.3–103.5). We also performed transurethral NOTES partial cystectomy with full-thickness bladder resection in the porcine model [25] (Figure 103.6).

Rectum/colon/intestine (transcolonic/transenteric)

An advantage of the rectum and colon as a natural orifice for NOTES access is its tolerance of relatively large scopes, such as colonoscopes. However, the high bacterial load of the colon makes this perhaps the most controversial access point, given the concern for potential infection, and it would require the ability to rigorously cleanse the bowel and effectively close the defect. Animal studies to date have included transcolonic cholecystectomy [32], ventral hernia repair, and distal pancreatectomy [33]. The only report of transcolonic access for a urologic procedure, to our knowledge, was a hybrid NOTES nephrectomy by Box *et al*. in the porcine model [34]. This group used a da Vinci S robot (Intuitive Surgical, Sunnyvale, CA, USA) to perform nephrectomy with combined transvaginal, transcolonic, and a single transabdominal trocar with transvaginal specimen removal [34].

Technical challenges

NOSCAR produced a White Paper in 2006 that identified a number of specific barriers to NOTES procedures. Challenges that were identified at that time included peritoneal access, maintenance of spatial orientation, access closure, control of hemorrhage, and development of suturing and anastomotic devices. The need for development of a multitasking platform was also identified [11]. While the primary focus at that time was limited to access from the gastrointestinal tract, these same issues would apply to vaginal and bladder access as well.

One of the immediately obvious technical challenges of translumenal procedures is that with the single access, a coaxial approach is necessary, which entails using

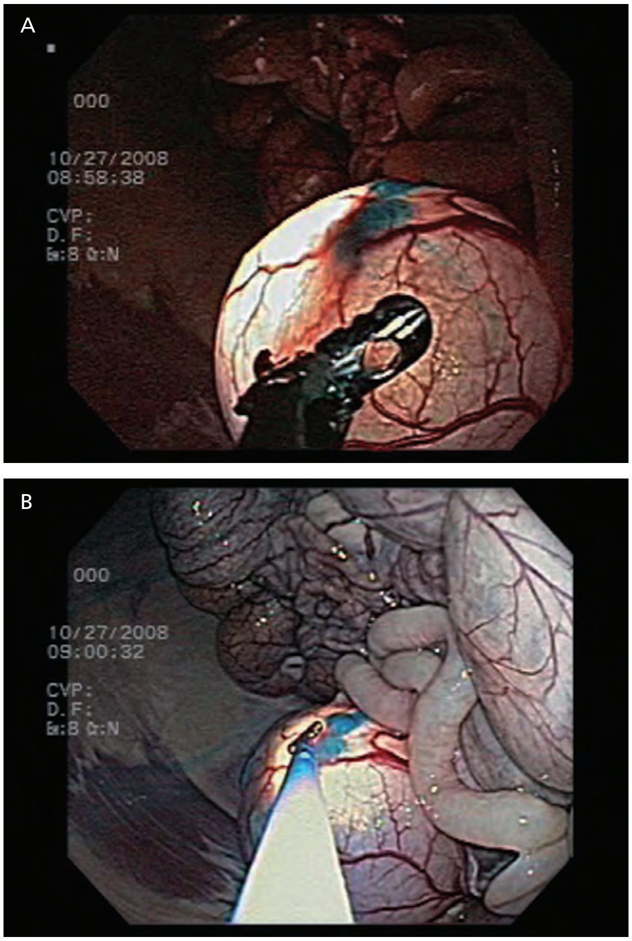

Figure 103.6 Transgastric NOTES Partial cystectomy using the R-Scope™ (Olympus, Tokyo, Japan) in the chronic porcine model. (A) Bladder is transilluminated with the cystoscope. Gastroscope bowel graspers are shown(B) An endoscopic loop is advanced to the bladder after preloading over the bowel grasper. Note that spatial orientation is difficult to maintain. In both these images the anterior abdominal wall is to the left and the fallopian tubes are to the upper right.

working instruments parallel to each other with limited ability to adjust the visual perspective. Urologists are already familiar with this concept, albeit to a lesser degree in the setting of bladder resections, stent removals, and ureteroscopic interventions such as basketing of stones. However, in contrast, all but the most basic therapeutic interventions typically require more than one instrument simultaneously, e.g. an instrument to retract while cutting.

Various strategies have been used for NOTES procedure to compensate for the coaxial limitations. One method is to obtain traditional triangulation by combining translumenal access points, such as combined transgastric and transvaginal access, or to use a hybrid NOTES approach. A disadvantage of the combined approach could include potential increased morbidity from additional access points and need for additional personnel.

Access

Establishing translumenal access while maintaining adequate sterility of the abdomen is a significant barrier, particularly for access from the gastrointestinal tract. The most clinically utilized translumenal access to date is transvaginal access, typically using a posterior colpotomy. Endoscopes can be inserted through the colpotomy and into the abdominal cavity either directly or with a preloaded overtube. An overtube allows easy reinsertion and exchange of instruments, although these are typically prototype devices, such as the modified trocar our group has used by attaching a plastic overtube to a standard laparoscopic trocar. The TriPort™ (Advanced Surgical Concepts, Wicklow, Ireland), for example, is a multiport device with a 15-mm gel valve and two 5-mm gel valves for laparoscopic instruments. The GelPort™ (Applied Medical) has also served as a multitrocar device for LESS procedures [35]. These combination devices have been used for some transvaginal NOTES procedures, including NOTES nephrectomy [36].

A modified PEG technique can be used for transgastric access with subsequent balloon dilation of the gastrotomy. For clinical use, this would likely require a multidisciplinary team that includes an endoscopist who is skilled with the gastrointestinal tract [13].)

Peritoneal access through the bladder is actually very simple to perform and could be the fastest method for access. Gettman and Blute described the initial human transvesical peritoneoscopy by introducing the ureteroscope after balloon dilation over a transvesical wire [26]. Our group routinely starts with a small incision in the porcine bladder using wire electrocautery, passing a wire through the vesicotomy, and then using balloon dilation over the wire to safely enlarge the incision with more control. However, a challenge using gas dilation of the bladder is a tendency for the bladder to collapse on itself if the defect is too large. In our experience, the porcine bladder is generally able to maintain its shape with dilation of the vesicotomy to 10 mm but not to 20 mm [37]. Lima's group used a 5.5-mm port for transvesical procedures using a ureteroscope in a porcine model [28], which is one approach to avoid the difficulty of bladder collapse and could allow periodic removal and insertion of the scope.

Establishing and maintaining pneumoperitoneum

Interestingly, for NOTES procedures, establishing and maintaining pneumoperitoneum has proven to be possible with even very small scopes such as the ureteroscope [26], pediatric gastroscope, and rigid cystoscope

[38]. However, in our experience, once instruments are inserted through the working channel, there can be a significant diminution in insufflation pressure, particularly with the smaller single channel scopes such as the pediatric gastroscope. There is also limited ability with current endoscope technology to regulate pressures, although some new platforms have addressed this problem. One solution is to use a transabdominal needle port for insufflation, although purists might consider this to be hybrid NOTES.

Use of conventional scopes

Much of the early work in NOTES has involved use of existing traditional endoscopic equipment. Important properties to consider in scope selection include scope size, flexibility, maneuverability, number of channels, channel size, ability to insufflate gas through the scope, ability to adequately illuminate the abdominal cavity, and ease of cleaning the lens. For most natural orifices, flexible scopes have proven to be advantageous and for transgastric access this property is essential to even reach the stomach perorally.

Most of the described scopes for transgastric or transvaginal access have been standard gastric endoscopes or colonoscopes with two channels, or pediatric gastroscopes with a single smaller channel. The standard gastric endoscopes have a number of advantages over other traditional scopes, including ability to maneuver both up/down and right/left separately, ability to self-clean the lens by depressing a button, and good illumination of the abdominal cavity.

Scope size is another important consideration. With the recent exception of procedures that used the combination port devices transvaginally, the scope is the sole conduit for instruments for most pure NOTES procedures to date. There is a tradeoff of between scope size and number and size of channels, as well as the size of the defect. We have found it is generally preferable to have at least two instrument channels that can accommodate standard endoscopic equipment for procedures that involve manipulation of tissues, assuming the scope is the only conduit for instruments. However, scope size affects possibilities for access. The small size of the urethra, for example, precludes introduction of even the smallest standard dual-channel adult gastric endoscope, although single channel pediatric gastroscopes can be used in our experience [38]. Very small scopes such as ureteroscopes introduced through the bladder may not even require closure of the defect [28].

Urologic scopes have had a more limited role to date, although a flexible cystoscope was described in Gettman *et al*.'s original paper for transvaginal access for nephrectomy [8]. Lima *et al*. described use of flexible ureteroscopes which are of ideal size but only accommodate small instruments [28], and our group described use of the standard rigid cystoscope, which provides reasonable illumination and two channels that each accommodate standard gastrointestinal endoscopic equipment [31]. Advantages of flexible scopes include maneuverability within the abdominal cavity and potential for retroflexion. For transvesical access, the standard gastroscope is too large for the urethra.

Additional challenges of traditional scopes include maintaining position of the scope as there is a tendency for the scope to recoil when pushing an instrument forward, which also affects transmission of forces. Spatial orientation can also be challenging with a tendency for flexible scopes, in particular, to rotate. This problem is most acutely obvious when the scope is retroflexed and the view may be turned completely upside down, which may be difficult or impossible to correct. As noted previously, traditional scopes often have coaxial limitations as well.

Endoscopic instruments

As with traditional open and laparoscopic surgeries, a variety of instruments are required to permit retraction, incising of tissue, dissection, and approximation of tissue. The challenge is to perform these tasks in a comparable manner to current standards with instruments that are small enough to fit through a small channel and which typically need to be flexible.

Grasping devices can be very helpful for manipulation of tissues. We have found the "rat-tooth" endoscopic forceps (FG-49L-1 grasping forceps; Olympus, Tokyo, Japan) to be helpful for manipulation of the bladder and bowel using the gastroscope and the rigid cystoscope (see Figure 103.6A). Endoscopic loop devices (e.g. Endoloop™; Ethicon Endo-Surgery, Cincinnati, OH, USA) can be used to entrap tissue prior to excision, such as a targeted area of bladder to be excised in NOTES partial cystectomy [25] (see Figure 103.6B)

Cutting of tissue with endoscopic instruments can be performed with needle knife electrocautery, snare wire cautery, or flexible endoscopic scissors. We have generally had better success with the first two options as the flexible endoscopic scissors have tended to be rather flimsy and difficult to use. It is hoped that industry may provide more robust scissors and other instruments in the future.

Several tools in the gastrointestinal endoscopic armamentarium are available for removing tissue. The most basic are a variety of flexible biopsy forceps similar to those used by the urologist cystoscopically, but with two basic differences: longer length to permit them to traverse the gastric endoscope and some have the ability to apply electrocautery directly with the forceps. As with cystoscopic biopsies in the bladder, these have a limited role for obtaining very small samples of tissue. For removal of larger tissues, the rat-tooth forceps can be used to directly grasp tissue specimens that have already been excised [25]. Alternatively, there are various endoscopic specimen retrieval devices traditionally used in conjunction with colonoscopy or esophagogastroduodenoscopy (EGD) procedures that may be adapted for NOTES procedures, including the Roth Net™ (US Endoscopy, Mentor, OH, USA) and the Nakao SpiderNet™ (ConMed Endoscopic Technologies, Utica, NY, USA) [39, 40].

Because of the need both for closure of access points and to allow performance of many surgical procedures, tissue approximation has been one of the most intense areas of focus for development. A variety of devices have been described for these purposes. The ideal would be a device that would allow intracorporeal suturing with ease. An early prototype described in the literature was the Eagle Claw™ (Olympus). More recently, the Food and Drug Administration (FDA) approved the OverStitch™ device (Apollo Endosurgery, Austin, TX, USA), which is attached to the end of the gastroscope and allows both running and interrupted suture. Various other manufacturers have produced devices that are intended to substitute for suturing. These typically involve placement of a suture and then instead of tying a knot, a fastening device cinches the two sides of suture together. These include the T-Tag™ system and TAS™ Tissue Approximation System (Ethicon), EndoStitch™ (Covidien, Mansfield, MA, USA), and the NDO Surgical Plicator™ (NDO, Mansfield, MA, USA) [39, 41, 42].

A simple device that has been successfully used for tissue approximation (including closure of translumenal access) is the endoscopic clip. This was originally intended to provide hemostasis or mucosal approximation [37, 41]. While many of these clips can rotate, some clips such as the Resolution™ (Boston Scientific, Natick, MA, USA) can open and close multiple times before deployment, which allows the closure to be assessed before committing. Our group has successfully used these clips for closure of small bladder defects. However, we have had poor results with very large bladder defects in a study of transgastric partial cystectomies with a high rate of adhesions, pelvic abscesses, and premature demise in a chronic porcine model. Stapling devices have also been developed for NOTES procedures. Experimental devices include the Intelligent Natural Orifice Linear Cutter or iNOLC™ (Power Medical Interventions, Langhorne, PA, USA), which is a power-actuated linear stapler with a flexible shaft [43].

Closure of access

As described in the above section, a number of devices are being developed for tissue approximation. However, effective and safe closure of the access gastrotomy remains the most significant barrier to human applications of transgastric surgery since a gastric leak could be a devastating complication. Many of the devices have been used experimentally to this end, including endoscopic clips [25, 41], various suture devices [41], the NDO tissue plicating device [42], and the flexible stapler [43]. Similarly, a transcolonic access would need to be reliably closed due to the high bacterial load and risk of severe infections.

Transvaginal NOTES incisions, by contrast, are easily closed under direct vision using absorbable suture and appear to be well tolerated. In 2001, Gill *et al*. reported 10 cases of transvaginal extraction of kidneys in patients who had laparoscopic nephrectomies [44]. This group described excellent patient satisfaction on postoperative questionnaire and the only adverse event was self-limited vaginal spotting in a single patient In one early clinical experience of transvaginal NOTES cholecystectomy, four patients reported little discomfort and morbidity, including lack of dyspareunia [45].

Closure of transvesical NOTES access should be an area of particular interest to urologists and may also be relevant to treatment of traumatic and iatrogenic bladder injuries. Intraperitoneal bladder injuries typically require closure, although small vesicotomies can be managed with simple catheter drainage [26]. In the NOTES literature, Lima *et al*. reported no complications of the unclosed vesicotomy in a chronic transvesical NOTES study using the ureteroscope [28]. Reliable methods of closing the bladder defect endoscopically, however, would be ideal. To this end, Lima *et al*. demonstrated successful bladder closure using endoscopically applied sutures in a chronic porcine model [46]. Our group also described the successful use of standard gastrointestinal endoscopic clips for closure in a chronic porcine model [25], although duration of clip attachment and potential for stone formation are potential issues with this technique.

Novel platforms

Various novel platforms have been reported for NOTES. Of particular interest are endoscopic platforms specifically designed for NOTES procedures, robotic platforms, and intracorporeal instruments, whether taking the form of magnetic instruments or miniature intracorporeal robotics.

Dedicated NOTES scopes

Several scopes have been developed specifically for NOTES. Traditional gastric endoscopes, while potentially useful for translumenal procedures, were specifically designed for the specific purpose of working within the lumen of the gastrointestinal tract and performance of relatively simple procedures such as removal of polyps. Meeting the new demands of NOTES for performance of complex procedures called for the development of new platforms with greater capabilities. A variety of concept scopes have been developed, including the Cobra™ (USGI Medical, San Clemente, CA, USA), which has three arms and the ability to lock shape, and the Viacath™ prototype scope (Hansen Medical, Mountain View, CA, USA) with articulating robotic arms [39]. Of the various new scopes, two in particular have reached commercial viability. The R-Scope™ (Olympus) resembles a standard gastroscope, but has two articulating sections and two elevators at the tip, one of which can be moved in the horizontal direction and the other in the vertical direction. The Transport™ (USGI Medical) can be locked into a given position, including in retroflexion, while maintaining the ability to steer the tip of the scope. The scope allows metered intraperitoneal insufflations and has two 6-mm and two 4-mm working channels [39]. Clayman *et al.* successfully used the Transport™ scope for a transvaginal NOTES nephrectomy in 2007 [47]. Certainly a concern with any novel platform will be the capital expense of new equipment for this purpose. The platforms developed to date are primarily applicable to transgastric, transvaginal, and perhaps transcolonic procedures, with no dedicated transvesical NOTES platforms described to our knowledge.

Robotic platform

The da Vinci robot (Intuitive Systems) has already been adapted for NOTES procedures, as previously noted for combined transvaginal and transcolonic hybrid NOTES nephrectomy [34] Haber *et al.* also reported use of the da Vinci system for transvaginal hybrid NOTES procedures, including nephrectomies, partial nephrectomies, and pyeloplasties [48]. While the da Vinci robot was not originally designed for NOTES, its use for this purpose is certainly a unique application of an existing technology. It can easily be envisioned that a future generation of robotics could be specifically designed for NOTES procedures. Canes *et al.* suggest there could be an increasing role for the robot in NOTES procedures, especially with further development of flexible robotics [49].

Internalized instrumentation

Instruments for laparoscopic and endoscopic procedures have always required both intracorporeal and extracorporeal portions in continuity, which limits the mobility and positioning of the internal portion. Two recent concepts have challenged the need for direct attachment between internal tools and the external means of manipulation with a new paradigm of independent internalized instruments: intracorporeal magnetic instruments and miniature internalized robots or "microrobots."

Magnetic instrumentation

A novel and exciting use of magnetic instrumentation was described by Cadeddu *et al.* [50]. Their "magnetic anchoring and guidance system" (MAGS) involves introducing instruments, such as cameras, graspers, and cautery instruments, through an incision and then manipulating them with an external electromagnetic coupling device. This MAGS system was successfully used in the laboratory for transvaginal NOTES nephrectomy and cholecystectomy, and for LESS nephrectomy. A magnetically anchored camera was used clinically for a LESS nephrectomy. The distance of the external coupler from the internal device can be a limitation, particularly in obese patients [50–54]. For NOTES procedures, the magnetic instruments would presumably be introduced through the natural orifice along with the scopes.

Miniature intracorporeal robotics

Miniature internalized robotic instruments may be mobile or stationary, but are controlled externally by remote control. Miniature robotic prototypes have typically had a single function, such as a camera, retraction or illumination [49]. Two camera prototypes have been described to assist laparoscopic prostatectomy in the laboratory. One prototype has a crawler functionality that provides internal mobility, while the other is stationary but provides a complete circumferential view of the abdomen [55]. These miniature robots have also been used in the setting of transgastric NOTES™ peritoneoscopy by Rentschler *et al.*, who proposed using a "a family of robots" working in conjunction [56]. A current limitation of these robots is battery life, currently limited to less than 1 h [49]. While further development is likely required before application to the clinical setting, these prototypes do demonstrate proof of concept and are encouraging.

Conclusions

NOTES is an exciting new approach to minimally invasive surgery and represents the extreme in scarless surgery by performance of surgery without cutaneous incisions. The field of urology has the potential to be impacted either endogenously or exogenously by application of NOTES techniques. Urologists may continue to adapt laparoscopic urologic procedures to a NOTES approach, and they may also have a collaborative role in transvesical NOTES procedures for nonurologic procedures (e.g. liver biopsies, gastric surgeries or cholecystectomies), potentially including transvesical access and closure and complication management. Additionally, many NOTES procedures may require collaboration of specialties that have not traditionally interacted, such as urologists and gastroenterologists.

It remains to be seen whether developments in LESS will be sufficiently channeled back to make NOTES in its purest form a viable clinical option in the future, and indeed whether potential advantages of NOTES could still outweigh any potential disadvantages of LESS. However, the recent description of a pure NOTES transvaginal nephrectomy in 2009 using a platform designed for LESS suggests that this could be the case [36].

Finally, there clearly are significant technical barriers to these approaches being adopted for widespread clinical use, despite promising early reports. Further developments have potential to overcome many of these challenges. We anticipate that various innovations will continue to be described both in the laboratory and clinically.

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CHAPTER 104

NOTES: Access and Exit

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Introduction

A paradigm shift in the approach to urologic surgery has occurred in recent years, with an ever-growing number of procedures being performed through fewer and smaller incisions. Natural orifice transluminal endoscopic surgery (NOTES) represents the next frontier in minimally invasive surgery. This approach permits access to the peritoneal or retroperitoneal cavity by making incisions in the stomach, bladder, or vagina rather than accessing the abdomen via skin incisions. Here, we detail the current understanding of access techniques utilized clinically and experimentally in transvaginal, transvesical, transgastric, and hybrid NOTES approaches. The chapter also highlights utilization of these approaches for urologic procedures as well as exit strategies for each approach.

Transvaginal NOTES

A transvaginal approach to surgery intuitively seems ideal, as many intra-abdominal organs can be accessed in a linear fashion. There have been several reports of successful urologic procedures performed transvaginally, with initial procedures tested in porcine models with subsequent transition to use in humans. In most described cases, pneumoperitoneum is acquired transabdominally through a Veress needle inserted through the umbilicus; however, it can also be achieved transvaginally after ports have been inserted through a direct vision colpotomy. For the exposure needed for transvaginal port placement, a combination of self-retaining vaginal retractors, Deaver retractors, and a weighted vaginal speculum may be used. A Foley catheter should be placed in all patients, and a rectal pack is optional. Multiple different ports and trocars have been used through the colpotomy with the transvaginal approach, as described below.

In 2002, Gettman *et al*. described transvaginal nephrectomy in a porcine model, the first experimental application of natural orifice surgery [1]. After establishing pneumoperitoneum transabdominally with a Veress needle, modified plastic fascial dilators traditionally used with the Amplatz dilating system (Microvasive; Boston Scientific Corporation, Natick, MA, USA) were used as transvaginal laparoscopic ports. The posterior colpotomy was balloon dilated to 24 F (UroMax II Plus, Microvasive) over a guidewire. A flexible cystoscope or standard 5-mm laparoscopic lens and camera were utilized transvaginally, and in some cases a traditional 5-mm transabdominal port was placed for the camera. Standard laparoscopic instruments and in some cases articulating instruments could be used through this access portal for dissection. The Endo-GIA stapler (US Surgical, Norwalk, CT, USA) was used transvaginally to divide hilar vessels and the ureter, and a 10-mm EndoCatch II device (US Surgical) was used to entrap the specimen.

Using a different platform, Clayman *et al*. also performed transvaginal nephrectomy in a porcine model

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[2]. Again, pneumoperitoneum was obtained transabdominally with a Veress needle. Transvaginally, a TransPort Multi-Lumen Operating Platform (USGI Medical, San Clemente, CA, USA) with four working channels (two 4 mm, one 6 mm, one 7 mm) was placed through a posterior colpotomy incised with an endoscopic needle-knife (Cook Medical Inc, Bloomington, IN, USA). Tissue-acquisition devices (g-Prox and g-Lix; USGI Medical) were used via the TransPort for retraction in combination with other endoscopic instruments. An additional 12-mm transabdominal port was placed to maintain pneumoperitoneum, confirm placement during transvaginal access, place a fan retractor, and apply a vascular GIA (Ethicon Endo-Surgery Inc, Cincinnati, OH, USA) for division of the hilar vessels. Although the TransPort allowed for multiple instruments to be utilized through a single port, drawbacks with this experiment included difficulty with triangulation and inability to secure the renal hilum through the channels in this platform.

In the first published description of NOTES transvaginal nephrectomy in a human, Kaouk *et al*. utilized yet another transvaginal port [3]. Pneumoperitoneum was established via the umbilicus through a Veress needle. Initially, a multichannel single port (TriPort; Advanced Surgical Concepts, Wicklow, Ireland) was positioned across the vaginal wall; however, these authors noted significant instrument clashing and subsequently exchanged the port for a GelPort (Applied Medical, Rancho Santa Margarita, CA, USA). Through this port, multiple trocars could be placed, which allowed for use of articulating instruments, a Hem-O-lok clip applier (Weck Closure Systems, Research Triangle Park, NC, USA), an endovascular stapler, and a laparoscopic retrieval bag.

In a cadaver study, Aron *et al*. utilized the QuadPort (Advanced Surgical Concepts) via a 3-cm colpotomy to perform transvaginal nephrectomy [4]. This port has an inner ring that is placed through the colpotomy and deployed to retain the port in place. The external ring is then cinched over the vulva, and these authors excised the redundant portion of the plastic sleeve. Pneumoperitoneum was then achieved through the gas inlet of the QuadPort. The channels in this port include one of 15 mm, two of 10 mm, and one of 5 mm. Through these channels, the authors used conventional straight and articulating laparoscopic instruments, with the endoscope placed through one of the 10 mm channels.

Another novel approach to transvaginal surgery includes incorporation of a magnetic anchoring and guidance system (MAGS), as described by Raman *et al.* for transvaginal NOTES nephrectomy in porcine models [5]. In this study, a 2-cm vaginotomy was made with electrocautery, blunt dissection was performed to create the rectovaginal space, the peritoneum was incised under direct vision via a gastroscope, and the gastroscope was advanced into the peritoneal cavity to allow air through the scope to create pneumoperitoneum. A rigid access port with a 26-mm outer diameter and 40-cm length was placed over a wire to replace the gastroscope, and the MAGS camera and cauterizer were deployed through the port. The MAGS system allows for manipulation of the camera and cauterizer independent of the transvaginal instruments, avoiding the “sword-fighting” of instruments traditionally encountered with single-port transvaginal access.

Transvesical NOTES

Similar to the transvaginal approach, the transvesical route obviates the limits of spatial orientation by allowing straight-line access to intraperitoneal organs. Clear limitations to the transvesical approach exist, including urethral diameter, urethral length, and potential need for urethral dilation with its inherent risks. There are few reports of pure transvesical NOTES; the access methods used are described here.

Use of the bladder as a portal of entry for NOTES was demonstrated in eight female pigs by Lima *et al.* in 2006 [6]. Under ureteroscopic guidance, the bladder was incised with Olympus A2576 scissors placed through the working channel of the ureteroscope. Next, a 5F open-ended ureteral catheter was advanced through the incision into the peritoneal cavity. Over a guidewire placed through the ureteral catheter, the cystotomy was dilated using the dilator of an ureterorenoscope sheath (Microvasive; Boston Scientific Corporation) encased by a flexible overtube. The ureteroscope could subsequently be passed through the overtube into the peritoneum, through which an Olympus UHI-3 insufflator was used to create pneumoperitoneum.

The first documented case of a clinical application of transvesical NOTES was performed by Gettman and Blute in a 56-year-old man prior to robotic prostatectomy [7]. With the patient in steep Trendelenburg position, a standard rigid cystoscope was placed transurethrally and a flexible injection needle was advanced through the bladder wall under simultaneous laparoscopic and endoscopic guidance (Figure 104.1). A balloon dilator (UroMax; Boston Scientific Corporation) was used to dilate the cystotomy tract. A flexible ureteroscope (DUR-8) was introduced through the cystotomy tract and transvesical peritoneoscopy was performed (Figure 104.2). Insufflation was successfully performed through the working channel of the ureteroscope to maintain pneumoperitoneum, and all intraperitoneal structures were visualized with a direct line of sight. After removing the ureteroscope, the cystotomy site did decrease in size but was not watertight; thus,

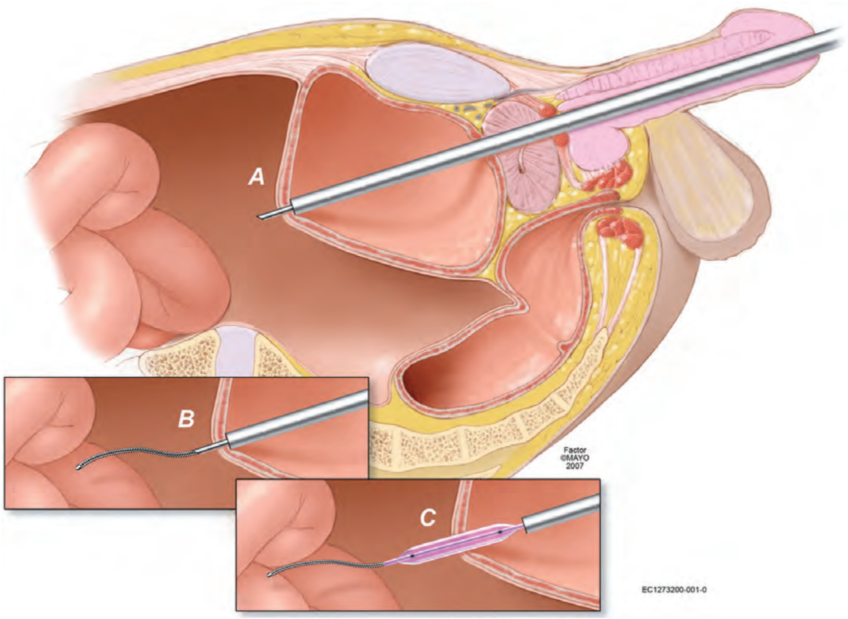
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Figure 104.1 (A) Standard rigid cystoscopy with a flexible injection needle advanced through the bladder wall. (B) A guidewire is advanced through the injection needle and (C) balloon dilation is performed to dilate the cystotomy tract. (Reproduced from Lima, E. *et al*. Endoscopic Closure of Transmural Bladder Wall Perforations, *European Urology* 2009; 56:1, with permission.)

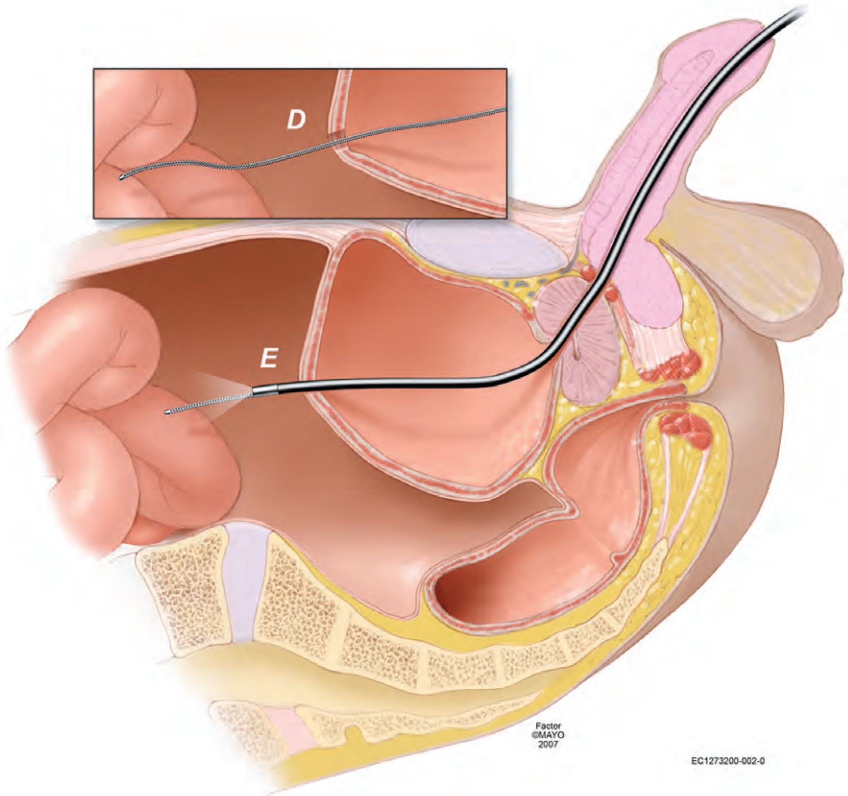
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Figure 104.2 A DUR-8 flexible ureteroscope is advanced into the peritoneal cavity over the guidewire (courtesy of Mayo-Rochester).

the site was closed with 2-0 Vicryl figure-of-eight sutures through laparoscopic ports.

Another urologic application of transvesical NOTES was described by Humphreys *et al*. to perform radical prostatectomy [8]. Access in this report consisted of urethral dilation to 30 F and placement of a continuous-flow 26 F resectoscope. A 100-W holmium: YAG laser was used to incise carefully through the capsule for extraprostatic dissection. In this approach, the neurovascular bundles and dorsal venous complex were spared. After completing dissection, the specimen was pushed into the bladder, morcellated, and vesicourethral anastomosis was performed using an offset nephroscope.

Transgastric NOTES

There is a risk of intraperitoneal contamination and infection due to exposure to gastric and bowel contents with oral approaches. Thus, many surgeons irrigate the stomach with saline or a disinfectant solution prior to puncturing or incising the gastric wall. Another limitation of gastric access is the inability to maintain spatial orientation. All instruments pass through working channels on the endoscope, with the light source and camera in line. During transgastric NOTES procedures, for example, some maneuvers require working off-axis, which further increases the difficulty of complex procedures. Most urologic applications for transgastric NOTES are in the setting of hybrid NOTES approaches, described below.

One gastric access technique, known as a blind needle-knife puncture [9, 10], begins with perforating the stomach on the anterior wall with a needle-knife or electrocautery under direct vision via gastroscope. Next, a guidewire is passed into the peritoneal cavity. The gastrotomy is then extended with an electrosurgical knife, sphincterotome, or a dilation balloon. After placing an endoscope (which can also be placed through an overtube), pneumoperitoneum is established with a laparoscopic insufflator connected to the accessory channel of the endoscope. In the balloon gastrotomy technique [10, 11], the gastrotomy puncture site is enlarged with a radially-expanding 20-mm balloon dilator, with subsequent advancement of the endoscope into the peritoneal cavity. Anterior wall access is preferred so as not to incur surrounding organ injury. A technical advantage of balloon gastrotomy versus a cut gastrotomy is a reduced risk of bleeding, as an expansile disruption of gastric tissue may be less traumatic to blood vessels. A limitation of this access technique is difficulty maintaining insufflation due to air leakage through the gastrotomy site.

Another technique, termed submucosal endoscopy with mucosal flap (SEMF), utilizes the submucosa of the gastric wall as a working space [12–14]. First, saline is injected to raise a submucosal bleb through which high-pressure bursts of CO_2 create a space in which blunt dissection is then used to separate the mucosa from the circular muscle layer. The submucosal space is then entered with the endoscope, and this is tunneled from 4 to 8 cm, and at the distal end of the tract a needle-knife is used to incise the seromuscular layer and the peritoneum is entered.

Crouzet *et al*. described renal cryoablation via transgastric access in a porcine model [15]. Pneumoperitoneum was first established transabdominally using a Veress needle. Next, gastrotomy was created by incising with the needle-knife followed by radially dilating with a 15-mm dilating balloon over a guidewire. A dual-channel video gastroscope (Olympus America Corporation, Center Valley, PA, USA) with an outer diameter of 13.2 mm and instrument channels of 2.8 and 3.7 mm was advanced. After dissecting through the gastroscope, cryoablation was performed percutaneously under gastroscopic vision.

Another group reported the feasibility of partial nephrectomy through a transgastric approach in a porcine model [16]. Pneumoperitoneum was gained using a transabdominal Veress needle, and a 2-cm gastrotomy was created using a diathermy electrocautery needle under gastroscopic guidance. This gastroscope (Olympus GIF-2T160) had an outer diameter of 12.6 mm and working channels of 3.7 and 2.8 mm, and could flex 210°, 90° down vertically, and 100° horizontally in each direction. After advancing the scope through the gastrotomy, a thulium laser (RevoLix; AllMed Systems, Pleasanton, CA, USA) was used to perform partial nephrectomy without hilar clamping.

Partial cystectomy via transgastric access was also reported to be successful by Sawyer *et al*. [17]. After needle-knife incision and advancement of a gastroscope near the bladder, endoscopic loop devices placed through working channels were closed to envelop the bladder specimen, and a needle knife and wire snare were used to cauterize an incision between the closed loops. The specimen was grasped and removed through the gastrotomy site.

Hybrid NOTES

There are many benefits to utilizing multiple natural orifices as access ports, termed hybrid NOTES surgery. Both portals can be used for introducing cameras, insufflation, and importantly instruments, overcoming the obstacle of lack of triangulation encountered in some single-access NOTES portals. Moreover, if one access portal precludes placement of certain instruments due to size limitations, use of an additional another access portal can allow for access.

Using a combined transgastric and transvesical approach, Lima *et al*. reported successful porcine nephrectomy [18]. A 5-mm camera was first placed transvesically using the access technique of Lima *et al*. [6], described above. Gastrotomy was established on the anterior wall with a needle-knife and cautery, and enlarged subsequently with a papillotomy knife. By alternating a rigid Olympus A2942A ureteroscope transvesically and a double-channel Olympus GIF-2T160 endoscope transgastrically, the working channels of both portals were able to be used for instrumentation. UltraCision Harmonic Scalpel Long Shears ultrasonic scissors were used via the transvesical port for dividing the renal artery and vein. In two animals, the ultrasonic scissors were insufficient to control the vessels, and a Ligamax five-clip applicator was successfully used to place clips for hemostasis. A major limitation in this study was the inability to close the gastrotomy portal safely. Additionally, instrumentation was limited for extraction; thus specimens were left *in situ*.

Isariyawongse *et al*. built on this concept, performing nephrectomy via a hybrid transgastric and transvaginal approach in a porcine model [19]. Transgastric access was obtained first, with subsequent pneumoperitoneum established through a single-lumen therapeutic gastroscope (Olympus EVIS Type 100 Q140). Under transgastric visual guidance, needle-knife electrocautery was used to create a transvaginal port for a 5.9-mm single-channel pediatric gastroscope (Olympus GIF XP-160). A novel laparoscopic trocar/endoscopic overtube was advanced over the transvaginal endoscope as the NOTES port and portal for continued insufflation. Standard laparoscopic instruments were used for dissection, and an Endo-GIA Universal 12-mm stapler (Autosuture, Covidien, Mansfield, MA, USA) was successfully used via the transvaginal trocar to divide the hilar vessels and ureter. The specimen was entrapped in a retrieval device (Endocatch Gold 10 mm; Autosuture) and removed through the vaginal incision.

The success of robot-assisted laparoscopic surgery as applied to urologic procedures prompted Box *et al.* to attempt a robot-assisted hybrid NOTES nephrectomy in a female pig [20]. A 12-mm transabdominal port was placed midline for use of the robotic camera as well as maintaining pneumoperitoneum. Two 12-mm standard laparoscopic ports (Ethicon Endo-Surgery Inc) were placed through the vagina and colon, with robotic ports telescoped through these ports upon docking of the robot. Robotic instruments (HotShears and ProGrasp) were used for dissection, and the hilum was divided using a vascular Endo-GIA stapler via the transvaginal port. The specimen was withdrawn through the vaginal incision. A significant limitation in this study was difficulty with robotic arm movement due to the proximity of the ports, which led to frequent collisions and "sword-fighting."

Haber *et al.* sought to overcome the lack of triangulation in previous NOTES procedures necessary for suturing by applying the robot to a hybrid transabdominal single port with a transvaginal port for dismembered pyeloplasty, partial nephrectomy, and radical nephrectomy in porcine models [21]. The transabdominal port consisted of either a single port with three channels (Uni-X; Pnavel Systems, Brooklyn, NY, USA) placed in the umbilicus or two ports (12-mm standard trocar and 8-mm robotic trocar) placed through a single 2-cm umbilical incision. Under laparoscopic vision, a flexible 12-mm cannula 20 cm long (US Endoscopy, Mentor, OH, USA) was placed as a transvaginal port, to which a robotic arm was attached. For pyeloplasty, EndoWrist needle drivers (Intuitive Surgical Inc, Sunnyvale, CA, USA) were used for the anastomosis. For radical nephrectomy, the renal artery was clipped and divided, and an XL Endo-GIA stapler (Covidien) was used to control the renal vein, with introduction of the clip applier and stapler via the vaginal port. For partial nephrectomy, the vaginal port served as an access point for introducing sutures, bolsters, and a laparoscopic bulldog (MicroFrance) for vascular control and renorrhaphy. Although collisions between the umbilical robotic arm and laparoscope still occurred in number of the cases due to their parallel alignment, the addition of the robot to NOTES provided a great advantage in providing three-dimensional vision, articulating instruments, and improved ability for intracorporeal suturing.

Exit strategies

Specimen extraction is an obvious limitation of NOTES procedures. A pure transgastric or transvesical approach may be ideal for purely reconstructive procedures, however extracting any sizable specimen through these portals is nearly impossible. Thus, alternative exit sites must be used. Additionally reliable closure techniques must be established.

Transvaginal exit strategies

A major benefit to transvaginal extraction is that a colpotomy can be extended to accommodate the size of the specimen, to a certain extent. However, this extraction technique is not only limited to female patients, but is typically excluded in those females who have had previous vaginal or pelvic surgery and in whom dissection may be limited by adhesions.

In the surviving animals in Gettman *et al.*'s initial porcine nephrectomy experiment, the vaginal incision was not closed but was left to heal by secondary intention due to small caliber and difficulty of closure with standard open techniques. Inspection of the incisions 1 week postoperatively revealed that the incisions had healed well [1]. However, concern exists regarding bacterial seeding of the peritoneal cavity and consequentially, infectious complications. Thus, the colpotomy is typically closed by hand in a single layer under direct vision, as has been done by gynecologists for years.

Transvesical exit strategies

A major limitation of utilizing the urethra as an access portal is size, which precludes extraction of large specimens. Additionally, potential risks of transvesical NOTES include fistula formation, infection, and peritonitis. Moreover, the effect of pneumoperitoneum in the urinary tract on kidney and bladder function is largely unknown.

Reliable bladder closure is also a concern with transvesical access. In most transvesical animal experiments, bladder closure was not attempted and the catheter was simply left in place. At necroscopy, it was observed that the vesicotomy sites had healed completely [6, 17, 18]. However, due to the concerns noted regarding fistula and infection, a dependable closure technique for the vesicotomy must be established. Furthermore, if primary healing of a vesicotomy is used, the benefits of a transvesical approach must be weighed against the morbidity of prolonged postoperative catheterization in patients.

Metzelder *et al.* described a technique for vesicotomy closure in piglets after transurethral NOTES nephrectomy [22]. A caveat to this closure is that it was not performed purely transvesically; rather, the procedure utilized a hybrid transumbilical and transvesical approach, and at the conclusion of the procedure an Endoloop device was used to close the bladder, while a 2-mm transurethral endoscopic clamp was used for assistance. At necroscopy, adequate bladder closure was tested using air-filling pressures and all closures were found to be impermeable.

Transgastric exit strategies

When transgastric NOTES initially emerged, there was significant concern for postoperative leak, fistula formation, and infection due to lack of adequate closure techniques. Although endoclips were initially used, this method typically only achieved mucosal closure. This technique has been employed in the submucosal tunneling approach [12]. However, full-thickness closure is the standard of care to prevent complications. Subsequently, several authors have reported on various gastrotomy closure techniques utilizing novel devices.

One group compared endoscopic clips versus over-the-scope clips (OTSC; Ovesco Endoscopy, Tübingen, Germany) for closure of an 18-mm gastrotomy in a porcine cohort [23]. Endoclips were applied through a double channel endoscope utilizing an Ovesco Twin Grasper (OTSC; Ovesco Endocopy) and Resolution clips (Boston Scientific Corporation). The OTSC technique employs traumatic gastric closure OTSCs, which have longer spikes that allow for anchoring of tissue. This group found that not only did the OTSC technique take significantly less time as compared to standard endoclips (mean 8.5 min vs 31.5 min, respectively), but the latter technique had an increased risk of leakage and intra-abdominal infections.

Full-thickness closure has been described using multiple different suturing devices. A suturing technology first described by Swain in 2003 involved a series of double T-tags positioned around the defect and advanced through the gastric wall [24]. The tags were approximated in pairs and locked to close the gastrotomy. This technique as well as its variations, although proven to provide an effective closure, was considered dangerous secondary to potential for inadvertent injury to surrounding organs [25, 26].

Desilets *et al.* described a modified T-anchor technique for closing the gastrotomy in a purse-string fashion in ex vivo porcine stomachs [27]. Metal wire loops were attached to T-anchors along which a 2-0 nylon suture was strung. Endoscopically, a transmural closure was achieved by placing the anchors into a slotted 19 G needle that had been advanced through the gastric wall, and pushing the anchor out of the needle with an inner stylet. By placing the anchors in a square around the gastrotomy, pulling tension, and applying a friction-fit collar and crimping device (Cook Endoscopy, Winston-Salem, NC, USA), the purse-string closure was completed. Another purse-string type of closure utilizes a device, Purse String Suturing (LSI Solutions, Victor, NY, USA), to aspirate the tissue containing the defect into a chamber, which invaginates the tissue [28]. Needles are then advanced through the tissue, creating a purse-string closure.

Another described gastrotomy closure method utilized a double-Endoloop technique (HX-400U-30; Olympus) in a porcine model [29]. Through a standard endoscope, an endoscopic grasper was advanced through an open Endoloop and one incisional edge was grasped and brought through the Endoloop, and the Endoloop was closed and released. This was repeated with the other edge of the incision, bringing the Endoloop around the stock of the first Endoloop. By tightening the second Endoloop, edges were reapproximated. The closure was tested with insufflation and found to be airtight. At necroscopy, evaluation of the closure sites found them to be well-healed without evidence of leak.

The Eagle Claw (Olympus), developed by the Apollo group, consists of a detachable needle attached to a curved holder with a mounted 3-0 nylon stitch. With jaw opposition, the defect is brought together by passing a needle through the tissue under direct endoscopic vision. The needle is then detached and the plication is completed by tightening the suture [30].

Stapling devices have also been used for gastrotomy closure. A linear stapler system (Surgassist; Power Medical Interventions, Langhorne, USA) consists of a flexible, 13-mm diameter shaft with a 55-mm stapler magazine which is deployed via an electronically controlled remote. Although closure has proven effective in *ex vivo* applications, a limitation of this device lies in the difficulty of manipulating tissue within the branches of the stapler [31]. Sherwinter *et al*. have subsequently reported on a modified circular stapler, a Surgassist powered circular stapler with a 213-cm flexible shaft [32]. A custom PVC auger-shaped tip attached to the anvil dilates the gastrotomy and allows the gastric wall to be loaded between the anvil and the staple cartridge. A novel modification of the device was to cover the staple cartridge with a loop of suture held in place by absorbable Vicryl mesh. After firing the stapler, the mesh is affixed to the outer portion of the viscerotomy, and the suture has been prepared for use as a purse-string closure. At the conclusion of the procedure, the suture is cinched under direct vision and locked using an endoscopic knotting device (TAS; Ethicon Endo-Surgery Inc).

Conclusions

Significant strides have been made in recent years in developing novel instrumentation to enhance NOTES procedures. The choice of access portal must be individualized to the organ of interest, need for specimen extraction, and obviously surgeon's expertise, as each orifice has inherent anatomic and technical limitations. Reliable closure of the access portal is another fundamental need with NOTES. In this regard, multiple innovative strategies have been introduced and evaluated both clinically and experimentally. For the future, clinical acceptance of NOTES will be in part dependent on the fundamental issues of safe entry to the abdomen and reliable closure of the access portal.

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CHAPTER 105

NOTES: Clinical Experience in Urology

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Introduction

Natural orifice translumenal endoscopic surgery (NOTES) has been gaining exposure and garnering more interest as an alternative, potentially less invasive approach to surgery. By performing surgery via a natural orifice, visible scars are eliminated, providing an obvious cosmetic benefit in addition to several theoretical benefits such as decreased pain, elimination of abdominal wall complications, and easier access (particularly in obese patients). This chapter will focus on the current clinical experience with NOTES in urology.

History

Performing surgery via a natural orifice is not new and in fact this dates back over a century. Gynecologists were gaining peritoneal access via the vagina to perform culdoscopy in the 1920s [1]. Urologists have been pioneers in natural orifice surgery, making a debut with transurethral surgery in 1877 with Nitze's cystoscope and in 1926 with endoscopic resection of bladder tumors [2, 3]. NOTES requires the intentional puncture of a hollow viscera in order to enter an otherwise inaccessible body cavity, so the aforementioned transurethral procedures would not be considered NOTES, but these experiences have served as part of the foundation for transluminal procedures [4]. It is the pioneering spirit of the urologic community that has kept urologic surgeons at the forefront of discovery and innovation, allowing them to continue to "push the envelope" and NOTES is no exception.

Transition to NOTES

The technical challenges encountered when performing NOTES using currently available instrumentation have been extensively described and include those secondary to the parallel insertion of instruments with a lack of triangulation, maintaining spatial orientation, inefficient traction, and indirect force transmission. As with any major change in surgical technique, there are several necessary transitions that should be undertaken to ensure the appropriate safety and efficacy of the technique. Experimental work in the lab on inanimate and animate models is necessary to demonstrate a reasonable level of feasibility. Ideally, this is followed by cadaveric studies to document this feasibility with more complex human anatomy. Finally, a careful stepwise clinical introduction should be undertaken. In general, this is the transition that has been seen with the clinical introduction of NOTES in urology.

Use of natural orifices: initial clinical experience

NOTES is certainly in its infancy as a surgical approach. As a result, most of the clinical reports in urology are either case reports or very small series. This section will

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review the published clinical applications of NOTES in urology.

Nomenclature

With any surgical procedure, new or old, there are invariably a variety of techniques and approaches to perform any given surgery. It becomes important to establish a standard nomenclature to ensure there is consistent and accurate reporting in the literature. This serves to both assist with future literature searches and to allow for a more appropriate comparison of techniques. The NOTES and LESS Working Group attempted to address these issues and have published a white paper on nomenclature [4]. NOTES was defined as a surgical procedure that utilizes one or more patent natural orifices of the body with the intention to puncture a hollow viscus in order to enter an otherwise inaccessible body cavity without the use of any transabdominal instrumentation. A procedure is considered hybrid NOTES if most of the procedure is performed via a natural orifice, but a transabdominal port is used at some point during the surgery. If a natural orifice is used as an additional port during laparoscopic surgery for insertion of an instrument or an endoscope for visualization, this is designated NOTES-assisted surgery. There is a logical stepwise progression from NOTES-assisted to hybrid NOTES to a "pure" NOTES surgical procedure as the level of difficulty can be expected to increase.

Urology and NOTES access

NOTES requires the surgeon to puncture an otherwise normal organ, which begs the question as to whether this is a reasonable thing to do. Aside from the extensive experience with transurethral surgery, urologists have also published several clinical reports of other organs serving as an entry portal for NOTES. These reports provide preliminary data to the feasibility and safety of a transluminal approach.

Bladder

The bladder is the obvious access portal for urologic investigation. Gettman and Blute were the first to report the clinical application of the bladder as a potential portal for NOTES [5]. At the time of robotic prostatectomy, under an Institutional Review Board (IRB)-approved protocol, a rigid cystoscope was use to advance an injection needle through the dome of the bladder under laparoscopic guidance. A guidewire was advanced through the needle and the opening was balloon dilated, which allowed for the introduction of a flexible ureteroscope into the peritoneal cavity. Peritonoscopy was performed and all intraperitoneal organs and structures could be visualized while maintaining the pneumoperitoneum via the working channel of the ureteroscope.

Vagina

The first transvaginal extraction of a nephrectomy specimen dates back to the early 1990s [6, 7]. A more recent experience was described by Gill *et al.*, who reported on a series of 10 patients who underwent laparoscopic nephrectomies with transvaginal specimen extraction [8]. The extraction added 35 min to the procedure, in large part because of the need to reposition the patient from the flank to the lithotomy position to retrieve the specimen. This was well tolerated by these women, who reported minimal discomfort related to the vaginal incision; in fact, all patients indicated their abdominal port sites were more painful that the vaginal extraction site. Furthermore, none of the sexually active women reported any change in their postoperative sexual function.

Colon

The urologic literature also contains some support for the use of a transcolonic approach. Degar *et al.* reported on a series of patients undergoing laparoscopic radical cystectomy with an intracorporeal rectosigmoid pouch [9]. There were six male patients in this series who had the specimen removed via the rectum. There were no reported infectious complications or any complications thought to be related to the transrectal specimen removal.

NOTES cadaver model

Aron *et al.* reported their experience with transvaginal NOTES nephrectomy using a multichannel port in a human cadaver model [10]. They planned to perform four transvaginal nephrectomies (two right and two left) on four fresh female cadavers. The cadavers were placed in the lithotomy position and a TriPort (Advanced Surgical Concepts, Wicklow, Ireland) was placed at the umbilicus to monitor the transvaginal procedure. A steep Trendelenburg was maintained as a posterior colpotomy was performed through which a four-channel QuadPort (Advanced Surgical Concepts) was inserted. The cadaver was then rotated 30–45° lateral, and standard and articulating laparoscopic instruments were placed through the QuadPort to perform the procedure. The authors commented on the difficulty in dissecting the upper pole of the kidney, in part because of the suboptimal visualization from the transvaginal portal and also from adhesions from previous surgery in two of the cadavers. Because of these difficulties, some

(~10%) of the procedure was completed via the transumbilical portal in both of the right nephrectomies. One of the attempted left nephrectomies was abandoned secondary to dense intra-abdominal adhesions from prior surgery. The other left-sided nephrectomy was completed with only transvaginal instrumentation as no transabdominal ports or instruments were used. The previously encountered problem with upper pole visualization was overcome by using a flexible gastroscope and bariatric length instruments during this step of the procedure. A standard laparoscopic stapler was used to divide the hilum in all cases followed by placement into a 15-mm retrieval bag and intact specimen extraction. The vaginal port placement took 20 min for the first case, but had decreased to 5 min by the last case. The nephrectomy portion of the procedure was completed in 115–133 min (mean total operative duration 170 min). The authors were able to complete a transvaginal NOTES nephrectomy in a cadaver without any transabdominal instrumentation. Some limitations were noted, including difficulties maintaining the pneumoperitoneum with the transvaginally placed QuadPort, particularly when a uterus was present. They demonstrated the feasibility of using conventional rigid laparoscopic instruments with a transvaginal approach, which overcome many of the limitations seen with flexible instrumentation, such as inefficient traction and indirect force transmission.

Clinical applications (Table 105.1)

NOTES-assisted procedures

NOTES-assisted surgery is a logical beginning in the ultimate journey to NOTES. Branco *et al.* reported a case of transvaginal NOTES-assisted laparoscopic nephrectomy [11]. In this case report, a 23-year-old woman with right flank pain and recurrent infections was found to have a nonfunctional right kidney and elected to undergo surgical removal. The procedure was performed with two 5-mm transabdominal ports, and visualization was provided with a flexible endoscope placed transvaginally via a posterior colpotomy, which was extended for specimen removal. No transvaginal port was utilized as the endoscope was placed directly through the colpotomy. The procedure was completed in 170 min with an estimated blood loss (EBL) of 350 mL. The patient had no complications and was discharged 12 h after the procedure, returning to normal activity on postoperative day 3. The authors noted difficulties with the flexible endoscope in terms of maintaining orientation and keeping the surgical field in view.

Alcaraz *et al.* reported a series of transvaginal NOTES-assisted laparoscopic nephrectomies [12]. Similar to the above case report, the authors used two transabdominal ports (one 5 mm and one 10 mm) in addition to a special bariatric trocar that was placed transvaginally. Visualization was provided with a deflectable-tip laparoscope placed via the transvaginal trocar. The procedure was completed in standard laparoscopic fashion with instruments placed through the transabdominal ports. The kidney was removed through the vagina after the posterior vaginal wall incision was extended; this was then closed with conventional instruments. Fourteen women underwent this procedure for a total of seven right and seven left nephrectomies with a mean operative time of 133 min and a mean EBL of 111 mL. One patient had a colon injury that required a diverting colostomy. The authors attributed this injury to multiple adhesions from previous surgery and did not think it was related to the placement or use of the transvaginal portal, but did highlight the importance of patient selection. Furthermore, they also noted difficulty retrieving the specimen transvaginally in patients who had a body mass index (BMI) greater than 30.

These reports help to establish the vagina as a viable portal and extraction site for NOTES. The NOTES-assisted approach allows surgeons to use a natural orifice as a portal through which to place an instrument or endoscope during a laparoscopic procedure, allowing them to become more familiar with the access and closure, while maintaining the ability to perform the surgery with standard laparoscopic techniques.

Hybrid NOTES

The next step in the transition to a completely NOTES approach is hybrid NOTES. Kaouk *et al.* reported a transvaginal hybrid NOTES nephrectomy in a 57-year-old woman with a right-sided atrophic kidney who was experiencing flank pain and elected to proceed with a transvaginal nephrectomy [13]. Insufflation was achieved with a Veress needle placed at the umbilicus. Following establishment of pneumoperitoneum, a posterior colpotomy was made. A previous hysterectomy had left many pelvic adhesions, so a 5-mm transabdominal port was placed at the umbilicus in order to place the transvaginal port under direct vision. A TriPort was placed transvaginally and the procedure was performed using a 5-mm 0° flexible-tip laparoscope, and 45-cm articulating laparoscopic instruments. During the dissection, ergonomic constraints were noted from the TriPort, so this was exchanged for a GelPort (Applied Medical, Rancho Santa Margarita, CA, USA) with a 12-mm and two 5-mm ports placed through it. The ureter was divided with clips and the renal vessels were individually divided with an endovascular stapler. In order to safely expose the hilum, the 5-mm transabdominal port was used to retract the colon during this

Table 105.1 Summary of clinical series of urologic transvaginal NOTES procedures.

Study	Institution	Procedure	Indication	Patients (n)	BMI	Operative time (min)	EBL (mL)	Transvaginal port	Accessory port(s)	Camera	Instruments	Complications	Length of stay
NOTES-assisted procedures													
Branco *et al*. [11]	Brazil	Right nephrectomy	Nonfunctional kidney	1	N/A	170	350	None	Transabdominal 5 mm X2	Flexible Endoscope	Standard laparoscopic	0	12 h
Alcaraz *et al*. [12]	Spain	Nephrectomy (7 right/7 left)	Renal mass (10) Renal atrophy (2) Stone disease (2)	14	N/A	133	111	10-mm bariatric trocar	Transabdominal 10 mm and 5 mm	Deflectable-tip laparoscope	Standard laparoscopic	1 (colon injury)	4 days
Hybrid NOTES													
Kaouk *et al*. [13]	Cleveland	Right nephrectomy	Atrophic kidney	1	26	307	100	TriPort and GelPort	Transumbilical 5 mm	5-mm deflectable-tip laparoscope	Articulating and standard laparoscopic (45 and 65 cm)	0	23 h
Sotelo *et al*. [14]	Venezuela	Left radical nephrectomy	6-cm renal mass	1	29.7	222	150	TriPort	Transumbilical TriPort	5-mm deflectable-tip laparoscope	Standard laparoscopic (extra long)	Fluid collection in renal fossa that required drainage	1 day
Zorron *et al*. [15]	Brazil	Left cyst decortication	9.5-cm symptomatic simple cyst	1	36.8	210	50	None	Flank 5-mm X2	Videocolonoscope	Polipectomy snare, monopolar biopsy forceps, and standard laparoscopic	0	4 days
NOTES													
Kaouk *et al*.[16]	Cleveland	Right nephrectomy	Atrophic kidney	1	32.3	420	50	GelPort and TriPort	None	5-mm deflectable-tip laparoscope	Articulating and standard laparoscopic (45 and 65 cm)	0	19 h

BMI, body mass index; EBL, estimated blood loss.

step. The rest of the kidney was freed with the use of an extra-long (65 cm) monopolar hook and placed into a retrieval bag, which was removed via the vaginal incision. The colpotomy was closed directly with Vicryl sutures. The surgery was completed in 307 min (124 min to obtain vaginal access). There were no complications and the EBL was 100 mL. The patient did well postoperatively and was discharged home on postoperative day 1.

Sotelo *et al.* described their experience with a hybrid NOTES transvaginal radical nephrectomy in a 65-year-old woman who was diagnosed with an incidental 6-cm enhancing central mass in the lower pole of the left kidney [14]. The patient was placed in lithotomy with a 45° right lateral decubitus position. At the start of the procedure, a TriPort was placed at the umbilicus. The posterior vaginal fornix was then entered using transabdominally placed laparoscopic instruments. A second TriPort was placed transvaginally and used to perform the majority of the dissection. A 5-mm 0° flexible-tip laparoscope was used to provide visualization and a combination of standard and articulating laparoscopic instruments were used to perform the procedure. The hilar dissection was performed utilizing the transumbilical portal for the camera and some laparoscopic assistance. The artery and vein were divided individually with clips and a vascular stapler, respectively, applied via the transumbilical port. The specimen was removed via the vaginal opening after being placed into a retrieval bag. The vaginal opening was then closed laparoscopically via the umbilical portal. The total operative time was 3.7 h with an EBL of 150 mL. The patient was discharged on postoperative day number 1 and resumed normal activity on postoperative day 3. The patient developed a fever requiring readmission and was found to have a fluid collection in the renal fossa that was drained percutaneously without sequelae.

The same group described in detail the work they had done leading up to this procedure, including the use of acute porcine and cadaver models [10]. Three other clinical cases were also attempted prior to this report, but all were ultimately converted to standard laparoscopy. It has been said before that we learn much more from our failures than we do from our success. It seems this was the case for these authors as the lessons learned were elaborated on and used for ultimate success. During the first attempted case, a rectal injury occurred during the insertion of the TriPort. Following this, the authors placed the transvaginal port under laparoscopic visualization. The second case was for an 8-cm upper pole right-sided tumor. This was converted because of failure to progress and highlights the importance of patient selection. During the third attempted case, bleeding was encountered with the suprahilar mobilization. Upon conversion to standard laparoscopy, an unexpected upper pole vessel was identified as the source of the bleeding, which stresses the importance of the use of extra-long instruments and the difficulties encountered when dissecting the upper pole of the kidney via the vagina.

Zorron *et al.* reported their experience with a transvaginal hybrid NOTES renal cyst decortication using a retroperitoneal approach [15]. A 67-year-old female presented with left-flank discomfort and was found to have a 9.5-cm left lower pole simple renal cyst. The patient was placed in the lithotomy position with Trendelenburg and a posterior colpotomy was made. The retroperitoneal space was developed with combined digital and endoscopic dissection. A two-channel videocolonoscope was used to perform the initial portion of the procedure and insufflation was achieved via one of the working channels. The scope was placed directly through the colpotomy and no port was used. During the retroperitoneoscopy, anatomic landmarks were identified, including the psoas muscle, vena cava, aorta, inferior mesenteric artery, and ureter. Gerota's fascia was encountered and opened with a polipectomy snare and the renal cyst was identified. At this point there was significant leakage of the pneumoretroperitoneum secondary to a tear in the peritoneum and two 5-mm laparoscopic ports were placed in the left flank to assist with the remainder of the cyst marsupialization, which was completed without complication. The vaginal entry portal was not closed because it was thought that the retroperitoneal structures would be unlikely to herniate through it. The procedure time was 210 min and there were no intraoperative complications. Postoperatively, the patient developed a small amount of pneumomediastinum that resolved with conservative management. Following the surgery, the patient's flank discomfort resolved and she denied any vaginal discomfort. This is the only clinical report in the urologic literature that attempted to use flexible endoscopes to actually perform the procedure. Most have abandoned these instruments in favor of standard laparoscopic instruments, which can be used with transvaginal surgery and are able to provide much more robust traction.

NOTES

Ultimately, Kaouk *et al.* were able to perform the first human urologic NOTES case without any transabdominal ports. They successfully completed a transvaginal NOTES nephrectomy in a 58-year-old woman who presented with recurrent urinary tract infections and was found to have an atrophic right kidney with 11% function [16]. She was placed in the lithotomy position with the right arm tucked over her chest and a wedge placed under her right side to place her in a slightly lateral position. The table was then rotated in order to provide additional passive retraction of the colon. A posterior colpotomy was performed and the peritoneal cavity was entered. Initially, a flexible gastroscope was introduced for a diagnostic evaluation and to confirm there were minimal pelvic adhesions. A GelPort was then placed transvaginally with two 10-mm and one 5-mm trocar placed through it. As described with their hybrid NOTES procedure, a 5-mm flexible-tip endoscope was used in conjunction with 45-cm articulating laparoscopic instruments. During the initial reflection of the colon, the downward torque placed on the GelPort resulted in a significant and problematic CO_2 leak that necessitated its exchange with the multichannel TriPort. The procedure progressed as it would for a standard laparoscopic nephrectomy. The ureter was divided with Hem-O-lok clips (Weck Closure Systems, Research Triangle Park, NC, USA). The GelPort was then reinserted and because the kidney was now being retracted laterally, no downward torque was needed, so there was no longer an issue with leakage of the pneumoperitoneum. The renal artery and vein were divided with an endovascular stapler. The remaining superior attachments were divided with an extra-long (65 cm) monopolar hook. The kidney was placed into a retrieval bag and removed via the vaginal incision. The vaginal incision was closed and a vaginal pack was placed. The procedure was completed in 420 min with an estimated blood loss of 50 mL. No transabdominal ports or instruments of any type were used at any point throughout the procedure, which makes this the first report of a "true" human NOTES nephrectomy. The patient was discharged 19 h after surgery and reported no pain on a visual analog pain scale (score 0 of 10).

Other considerations

Patient perspective

NOTES represents a major change in the traditional approach to surgery, so patient acceptance is an important consideration. At present, the transvaginal approach appears to provide the best opportunity for clinical NOTES in urology. Women have been surveyed as to their views and acceptance of a proposed transvaginal procedure. Peterson *et al.* surveyed 100 women to obtain their opinions and define their concerns [17]. The women were given a written description of standard laparoscopic surgery and NOTES, and were then asked to respond to a 10-question survey. Sixty-eight percent indicated if data showed the equivalency of NOTES that they would prefer a transvaginal approach. The reasons given for this decision included cosmetic reasons (61%), to minimize hernia formation (90%), and to minimize pain (93%). Regarding potential complications, concerns included infectious issues (83%), impact on sexual health (81%), and effects on fertility (61%). The women who preferred the NOTES approach were more concerned with cosmesis, hernia formation, and pain. Those who did not want a transvaginal procedure were most concerned with infectious issues.

Another survey of 300 women was reported by Strickland *et al.* [18]. This questionnaire also focused on their opinion regarding NOTES versus standard laparoscopic surgery. Interestingly, 66% of this group of Australian women indicated they did not dislike scars after a surgical procedure. Not surprisingly, this feeling was less prevalent in younger women. Most women (72%) indicated they would be neutral or unhappy with the prospect of NOTES. When asked which type of procedure they would prefer, 65% indicated they would prefer standard laparoscopic surgery.

These and other surveys indicate that while there is public interest in NOTES, the procedure-related risks, pain, and recovery time seem to be the most important priorities for patients [19].

Multidisciplinary team

Many of the quantum leaps in surgery have resulted from the collaborative efforts of physicians across disciplines, as was the case with the first laparoscopic nephrectomy. It is this collaboration that often allows for the most creative solutions to problems encountered, as each member has a unique perspective to share. Many of the initial reports of the clinical application of NOTES in urology have benefitted from this collaboration with gynecology and general surgery colleagues.

Institutional Review Board

NOTES is still an experimental technique that must only be performed with the upmost emphasis on patient safety. The often spoken dictum of "first do no harm" certainly applies here. NOTES is very early in its development and the available instrumentation and technology are lagging far behind the ideas that have been conceptualized. As with all innovation, the introduction of a new procedure or surgical approach must be cautious so that patient harm is minimized. At least in theory, NOTES seems to represent a potential paradigm shift in surgery, similar to the way laparoscopy forever changed the surgical landscape more than 20 years ago. It is this great potential that makes its introduction into clinical practice even more challenging. As with any new procedure with an unproven feasibility or safety record, IRB approval is mandated prior to performing NOTES clinically.

Relationship of LESS and NOTES

The development of laparoendoscopic single-site surgery (LESS) and NOTES will likely prove to be mutually beneficial in the future progress of both of these techniques. In fact, in urology it seems this is already the case to some extent. The recent interest in urologic NOTES has lead to the rapid realization that the available endoscopic instrumentation is woefully inadequate for the majority of urologic intra-abdominal procedures. Almost simultaneous to the introduction of NOTES, there has been an explosion in the interest in LESS. The clinical experience with LESS is now quite extensive and the rapid assimilation of LESS is likely due to its similarity with standard laparoscopic surgery in terms of technique and instrumentation. As experience with LESS has grown, it became apparent that this technique and instrumentation could be used for NOTES, particularly if performed via a transvaginal approach, which would allow for the use of rigid instruments. Most of the reported clinical NOTES cases have used the same ports and instruments that are commonly used with LESS. It appears the experience with LESS facilitated the clinical introduction of NOTES in urology. It is likely that this relationship will continue to prosper as new purpose-built instrumentation is developed. A small flexible robotic platform can certainly be imagined that could be inserted through a small abdominal incision to perform LESS and, eventually, through a natural orifice to perform NOTES.

Clinical role in urology

NOTES is an experimental technique that is in its infancy. While a human transvaginal NOTES nephrectomy has now been successfully achieved, the ultimate role NOTES will have in urology is unclear. This will depend on multiple factors that include patient acceptance, instrument development, and a proven feasibility and safety record. Regardless of the final fate of NOTES in urology, physicians and patients are sure to benefit. The recent interest in NOTES will hopefully push industry to develop better and novel instrumentation. While NOTES is certainly deserving of additional investigation, the ultimate role it may play in the management of urologic disease remains to be determined.

Conclusions

The clinical use of NOTES in urology has been extremely limited to date largely due to the well-recognized lack of appropriate instrumentation. Human ingenuity will eventually meet the technical challenges currently found with the available instrumentation. Continuing the innovative efforts to modify and improve existing surgical equipment and technology will no doubt benefit future patients, regardless of the approach.

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CHAPTER 106

Laparoendoscopic Single-Site Surgery: Ports, Access, and Instrumentation

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Introduction

The prevalent implementation of laparoscopy has introduced a new era in surgery. Lately there has been a push to further reduce the invasiveness of laparoscopic surgery. To facilitate this goal, surgeons have proposed limiting the number of abdominal incisions with laparoendoscopic single-site surgery (LESS) or eliminating them completely through natural orifice translumenal endoscopic surgery (NOTES) [1]. The latter has been demonstrated primarily in preclinical animal models with limited experience amassed in clinical series; as such, the human experience with this technique is still experimental [2–6]. Conversely, LESS has undergone laboratory and clinical work and has proven to be feasible and applicable to humans [7–12].

LESS is not new and has been documented in the literature since 1997 for various specialties, including general surgery and gynecology [13, 14]. Widespread acceptance of this technique did not occur due to the limitations experienced with the current technology available at that time. Current innovations such as articulating instrumentation and novel multilumen ports have fostered a renaissance for LESS with several recent clinical series reporting successful completion of a range of procedures [8–12]. The proposed benefits of LESS include improved cosmesis and reduced postoperative pain.

Over a relatively short period of time, LESS has undergone an evolution including updates in port, instrument, and scope design. Initially, LESS was performed through a single incision with multiple trocars placed through separate fascial stabs, but in an attempt to reduce fascial trauma, multichannel laparoscopic ports were developed. An effort to overcome clashing and lack of instrument triangulation, experienced with straight laparoscopic equipment, has led to the development of prebent, flexible, and articulating instruments. Finally, advances in optical technology have allowed for smaller diameter lenses, improved resolution, ability to deflect, and lower profile built-in cameras.

Special technical considerations

Transperitoneal LESS procedures

Transperitoneal LESS procedures may require adjustments regarding instrumentation and positioning. Longer instruments may be necessary, especially with larger patients and during adrenalectomy, to account for the low placement of the port through the umbilicus. Articulating instruments may also be the equipment of choice due to the large operating space and the need to access all angles of the operative field. It is also more likely that a longer telescope with a flexible tip is needed to visualize target organs.

Retroperitoneal LESS Procedures

The retroperitoneum is a smaller space and is therefore more prone to instrument crowding and clashing. Shallower ports are often better to use as they function-

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ally increase the operative field. Use of flexible or bent instruments may minimize clashing of instruments.

Obese patients

There are several technical caveats that may be useful when performing LESS urologic procedures in obese patients. More of a full-flank (90°) position is required in obese patients versus a semi-flank position (45–60°) for the nonobese during upper tract procedures. This allows for displacement of the pannus away from the surgical field and further helps displace bowel medially. The bony anatomic landmarks, including the anterior iliac spine and pubic symphysis, are critical to maintain midline orientation. This is especially important for the patient with a pendulous pannus that shifts the umbilicus significantly towards the pubis. While the access site for transperitoneal procedures is typically placed in the umbilicus, the patient's abdomen is either lifted with padding or fixed with 3-inch cloth tape so that the umbilicus is lifted into a more anatomic position prior to starting surgery. Additionally, longer instruments may be necessary and a higher insufflation pressure needed to account for the added weight of the abdominal wall.

Ports

In its truest form LESS represents laparoscopic surgery performed through a miniaturized incision at a single site. Even though these procedures are commonly performed via a commercially made single port, the term "single port" is avoided because these procedures can be performed through a small incision with multiple trocars. Additionally, standard trocars can be added adjacent to the commercially available "multichannel ports," through the same skin incision but into a separate fascial stab in a hybrid format. This is particularly helpful during robotic LESS (R-LESS). There are several single port devices available, each with their own advantages and disadvantages (Table 106.1).

Multiple trocar configuration

This trocar configuration consists of a single skin incision with several ports placed through separate fascial sites. The cannulas are bunched together with contact between the external housings. Piskun *et al.* were the first to report utilizing multiple trocars through a single transumbilical incision to perform a cholecystectomy [13]. Two separate 5-mm trocars were placed through an intraumbilical incision via two separate fascial stab incisions. The procedure was performed and the specimen extracted after the fasciotomies were joined, leaving a near scar-free appearance. Raman *et al*. subsequently used multiple trocars through a single incision with three separate fascial stab incisions for urologic purposes. They were able to complete two of three nephrectomies without adding additional trocars and found "the single trocar to be more cumbersome with fewer degrees of freedom than three adjacent trocars" [7]. The multiple trocar configuration can be performed with traditional 5-mm trocars or specifically designed kits.

AnchorPort™

The AnchorPort (Surgiquest, Orange, CT, USA) was created in an effort to reduce external cannulas clashing (due to bulky 5-mm external cannula housings) and improve range of motion. AnchorPort's small and low-profile housing allows cannulas to be placed close together (Figure 106.1A). Additionally, the ports contain an internal anchor which prevents them from dislodging. Lastly, optical entry can be used on all entries, not just the first.

Multichannel laparoscopic ports

The multichannel laparoscopic port is placed through a single skin and fascial incision. The ports are placed via an open (Hasson) technique, primarily through the umbilicus.

R-Port/Triport/Quadport

The TriPort and QuadPort (Advanced Surgical Concepts, Wicklow, Ireland) represent an evolution of the R-Port and have been used extensively in LESS [8, 10, 12, 15–24]. They differ in the number of available operative inlets and overall size, but otherwise are identical. The devices consist of a retractor and valve. The retractor consists of one internal ring and two external rings, and a double-over cylindrical plastic sleeve; the latter is attached to the inner ring of the two external rings and descends, circles the inner ring, and exits between the two outer rings. The valve component incorporates three or four inlets for introduction of instruments. The three-inlet valve (TriPort) has one inlet for a 12-mm instrument and two for 5-mm instruments. The larger version (QuadPort) has two inlets for 12-mm and two inlets for 5-mm instruments (Figure 106.1B).

SILS™ port

The SILS port (Covidien, Cupertino, CA, USA) is a new introduction to the field of LESS. The SILS port is a flexible laparoscopic multichannel port that can accommodate up to three instruments through a single incision. It is made of soft foam that is designed to conform to

Table 106.1 Available single port devices.

Access device	Features	Advantages	Disadvantages
TriPort (Olympus)	Flexible multichannel valve; up to three instruments (1 × 12 mm; 2 × 5 mm); covered with an elastomer	Adapts to incision and abdominal wall thickness	Fragile when using 12-mm Instruments Lubrication required Constrictive outer ring Gas leakage
Quadport (Olympus)	Flexible multichannel valve; up to four usable instruments (1 × 15 mm, 1 × 10 mm, 2 × 5 mm); covered with an elastomer	Adapts to incision and abdominal wall thickness	Fragile when using 12-mm instruments Lubrication required Constrictive outer ring Gas leakage
SILS port (Covidien)	Flexible platform; up to three individual ports and instruments	Easy exchange of different size ports	Difficult to use with large abdominal wall
GelPoint (Applied Medical)	Three components: GelSeal™ providing PseudoAbdomen™ platform; Alexis™ wound retractor; self-retaining trocars	Larger outer working profile for enhanced triangulation Adapts to incision and abdominal wall thickness	Fragile Gas leakage during prolonged procedures
AirSeal (Surgiquest)	Oval valveless cannula with invisible pressure seal	Stable CO_2 pressure Multiple instrument insertion	Rigid; less freedom of movement Noisy
AnchorPort (Surgiquest)	Low-profile ports of various lengths placed in close proximity	Anchoring system Optical entry	Rigid; less freedom of movement
Homemade	Alexis™ wound Retractor, Latex glove, variable ports	Inexpensive Larger outer working profile for enhanced triangulation Adapts to incision and abdominal wall thickness	Must be built for each case
Octo-port (Dalim SurgNET)	Wound retractor, three flexible caps, three cannulas, two channels for insufflation and smoke evacuation	Adapts to incision and abdominal wall thickness Multiple caps allow for tailoring of procedure	Fragile when using 12-mm Instruments Lubrication required Constrictive outer ring Gas leakage
SSL Access System (Ethicon Endo-Surgery)	Wound retractor, 360° rotation of the seal cap, three entry points, insufflation channel	Quick reorientation of instruments during procedures, reduced need for instrument exchanges	Rigid; less freedom of movement
X-CONE (Karl Storz)	Two-piece design, flexible cap, three cannulas	Reusable Easy to place	Gas leakage from cap Two pieces disengage

the contours of the incision. It contains a built-in insufflation valve and three port sites that can accommodate two 5-mm cannulas and a single 12-mm cannula (Figure 106.1C). The SILS port has been reported for various surgeries [25–27].

GelPort™/GelPoint™/Alexis™

The GelPort laparoscopic system (Applied Medical, Rancho Santa Margarita, CA, USA) combines a GelSeal cap with the Alexis wound retractor. The GelSeal cap attaches to the wound retractor by means of a latch. Designed for hand-assisted laparoscopic procedures, the GelPort has been used during LESS and R-LESS procedures [27–29]. Multiple trocars of varying size can be introduced through the GelSeal cap and the specimen can be extracted once the GelSeal cap has been removed.

The GelPoint represents the evolution of the GelPort™ and is designed specifically for LESS (Figure 106.1D). It has a smaller gel cap and four premade self-retaining 5-mm trocars, though various sized trocars can be placed similar to the GelPort. Additionally, there is an insufflation port built into the side of the device and the Alexis wound retractor is fitted with a tether for easier removal.

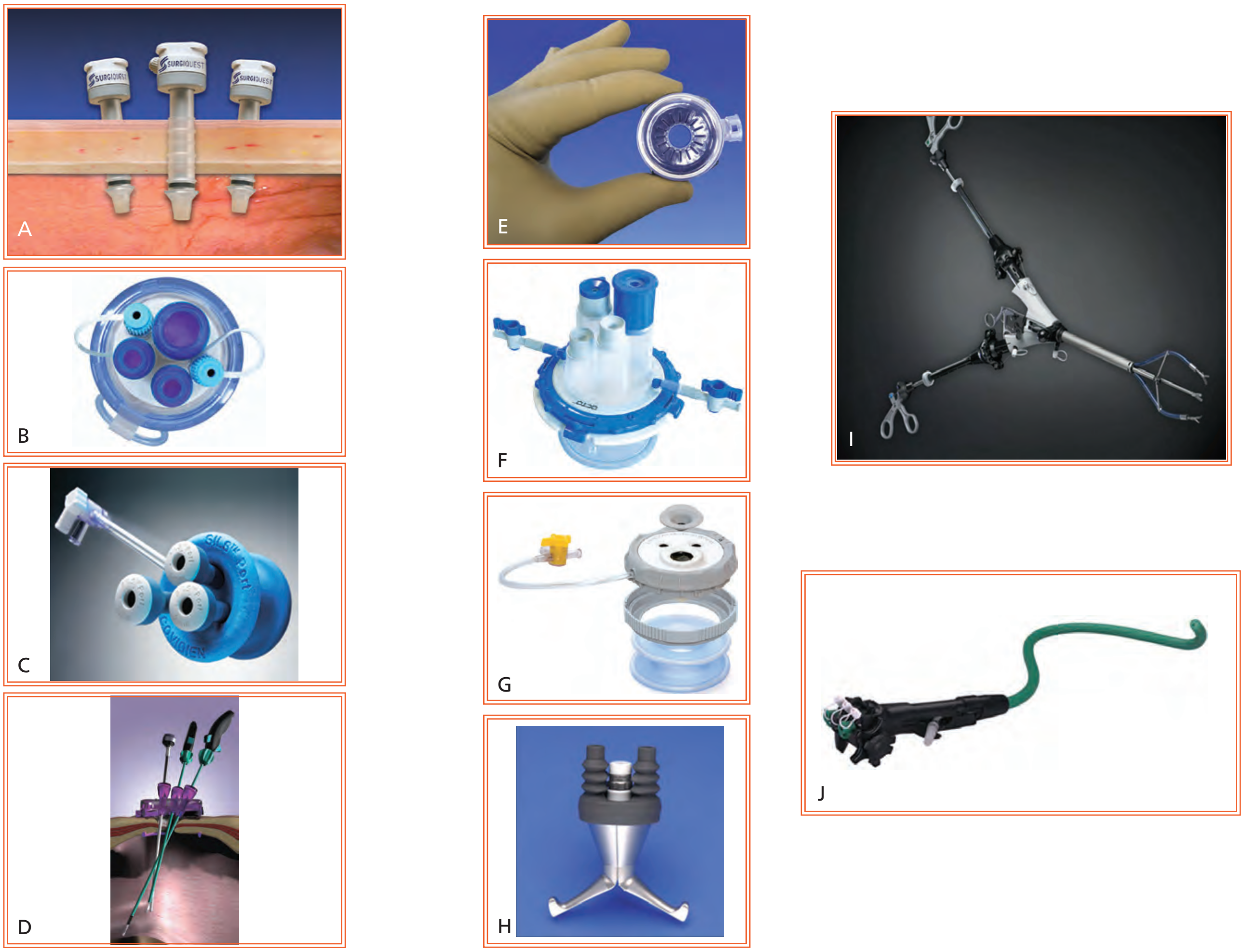

Figure 106.1 Commercially available multichannel laparoscopic ports. (A) AnchorPort (Surgiquest, Orange, CT, USA), (B) R-Port/TriPort/QuadPort (courtesy of Advanced Surgical Concepts, Wicklow, Ireland), (C) SILS port, (D) GelPoint (photo courtesy of Applied Medical Resources), (E) AirSeal, (F) Octo-Port (courtesy of DalimSurgNET), (G) SSL Access System (courtesy of Ethicon Endo-Surgery Inc, Cincinnati, OH, USA), (H) X-CONE, (I) SPIDER Surgical Platform (H, I, courtesy of TransEnterix Inc, Durham, NC, USA), (J) TransPort.

AirSeal™

AirSeal (Surgiquest) is a technology which recirculates and filters peritoneal gas. It removes smoke from the field of vision and filters it, instead of venting it into the room. There are no valves or gaskets required, so multiple instruments and a camera can be inserted without a reduction in pneumoperitoneum. It consists of a single port with a rigid external housing and an oval cannula (Figure 106.1E). The system monitors and allows the insufflator to adjust as needed to ensure a stable pneumoperitoneum.

Octo-Port™

The Octo-Port (Dalim SurgNET, Seoul, South Korea) consists of a self-retractor that retracts the abdominal wall and protects the incision. The retractor varies in size from 1 to 5 cm. Three caps are available that attach and provide a different array of cannulas. The large caps contain two separate channels that allow for insufflation and smoke evacuation. Two configurations are available for single-site surgery: a cap with two 10/12-mm cannulas and a single 5-mm cannula; and a cap with one 10/12-mm cannula and two 5-mm cannulas. The cannulas are different heights to prevent external clashing and the cap is flexible to allow for an improved range of motion (Figure 106.1F).

Ethicon Endo-Surgery SSL Access System

The SSL Access System (Ethicon Endo-Surgery Inc, Cincinnati, OH, USA) is a single-port access device that consists of a wound retractor and a cap that attaches via an attachment ring. The cap has two 5-mm seals and a larger 15-mm seal in a low profile design. An additional channel found on the cap allows for insufflation. The integrated seal system does not require trocar use, possibly eliminating interference of trocar cannulas in the abdominal cavity. Unique to the device is the 360° rotation of the seal cap, which enables quick reorientation of instruments during procedures and reduces the need for instrument exchanges (Figure 106.1G).

X-CONE

The X-CONE (Karl Storz Endoscopy America, El Segundo, CA, USA) is a reusable access device for transumbilical laparoscopy. It consists of three working channels that permit the introduction of instruments of up to 12.5 mm in size. A plastic, but flexible, cap with three entry sites attaches to the two-piece metal device. Special curved instruments are encouraged with this device in addition to an extra-long endoscope. It is introduced via a Hasson technique in two pieces that then snap together (Figure 106.1H).

Homemade single-port device

Commercially produced single ports are not universally available and have pushed surgeons to create their own access devices [30–33]. These access devices consist of the Alexis wound retractor, a sterile surgical glove, and standard laparoscopic ports (Figure 106.2). The size 7 surgical glove is attached to the wound retractor and three to four of the finger tips are removed so the cannulas can be inserted and tied in place. Insufflation is performed through the previously placed ports.

Multichannel hybrid laparoscopic ports

The multichannel hybrid laparoscopic port is a complete system that behaves more as a surgical platform than just a port. The multichannel hybrid laparoscopic ports require specialized instruments (flexible gastroscope, etc.) and have been conceived as much from NOTES as they have from LESS. These ports are placed through a single skin and fascial incision using the Hasson technique.

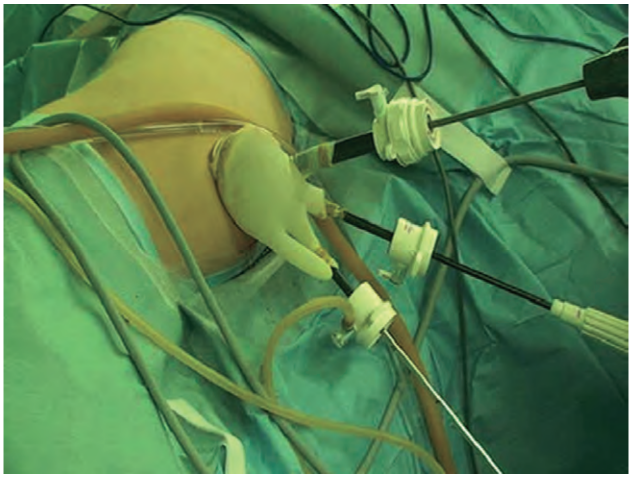
Figure 106.2 Homemade multichannel laparoscopic port.

SPIDER™

The SPIDER Surgical Platform (Trans Enterix Inc, Durham, NC, USA) is a single-port access device that requires special instrumentation to perform LESS. It is available in two models and consists of an insertion trocar that guides the distal end into the abdominal cavity and four working channels (Figure 106.1I). Two flexible channels, known as IDTs (instrument delivery tubes), facilitate motion to allow for a multidirectional and triangulated approach within the surgical field. The flexible IDTs are guided by a gimbal system at the proximal end, which provides 360 degrees of freedom at the distal tips. Crossing of instruments is not necessary and therefore the left hand controls the left instrument and the right hand the right instruments. Two rigid channels positioned vertically to the operative field accommodate the use of a scope and any other rigid surgical instrument. Three pneumoperitoneum/vacuum ports exist to maintain pneumoperitoneum and facilitate insufflation and/or smoke evacuation. There is a docking ball that attaches the SPIDER device to the stabilizer. The stabilizer must be purchased separately and attaches to the operating table.

TransPort™

The TransPort (USGI Medical, San Clemente, CA, USA) provides stable access to the operating site via one of the body's natural orifices or an incision in the umbilicus. The TransPort is more akin to a gastroscope/colonoscope than a standard laparoscopic instrument. It has four large working channels, one for an endoscope and three others for large diameter instruments (Figure 106.1J.). This device creates the multitasking platform and utilizes a flexible endoscope along with multiple flexible endoscopic instruments.

Laparoscopic access

Transumbilical

Transumbilical access is the standard for LESS procedures. The umbilicus affords direct entry into the peritoneal cavity and readily hides the surgical scar. Various incisions can be used, including intra-, infra-, supra-, and peri-umbilical. The incision length is chosen based on the minimum amount of space needed to accommodate the desired port or trocar configuration. The incision is made through the skin and dermis and carried down to the rectus fascia. For the multiple trocar configuration, the fascia is grasped, elevated, and pneumoperitoneum is achieved with the Veress needle technique. The chosen trocars are then inserted into the abdomen. The AnchorPort system is inserted in a similar fashion, yet optical entry (placement of a 5-mm scope and camera through the port) can be used on all entries, not just the first. The AirSeal single port is inserted in a comparable fashion to a standard optically placed trocar except that a specially designed hand piece allows for an off-set hand position to help guide the cannula.

The TriPort and QuadPort require that a series of manufacturer directions are followed to enable accurate placement. This system can be placed in a closed Veress needle fashion, with an enlarged fascial incision, or with the open Hasson technique. First, the distal ring is loaded into the introducer. The introducer then bluntly dissects through the abdomen. Once through the peritoneum, the thumb-switch on the introducer is depressed and the distal ring is deployed. The introducer is then removed and the sleeve is pulled upwards to bring the internal ring into contact with the inner abdominal wall. The outer ring is then pushed down to create further retraction. The excess sleeve is removed and slack in the port is removed with the retracting ribbon. Insufflation is attached to the appropriate cannula to create pneumoperitoneum.

The SILS port, GelPort/GelPoint, Octo-Port, SSL Access device, X-CONE, and the handmade device are inserted into the abdomen in a similar fashion. After the umbilicus has been dissected free of the rectus fascia, and the preperitoneal fat visualized, entry into the abdomen is gained bluntly with either a finger or handheld clamp. The incision in the fascia is then enlarged by at least 1.7 cm up to 7 cm. The Alexis wound retractor is inserted through the fascia and care is taken to avoid entrapping bowel when folding the retractor. Both the gel cap of the GelPort/GelPoint or surgical glove of the handmade port is fixed into place and insufflation is begun through the attached cannula or a preinserted laparoscopic trocar. The fascial incision for the SILS port should be no larger than 2 cm to create a good seal and maintenance of pneumoperitoneum. The flexible SILS port is folded at its lower edge (contralateral to the insufflation system), and with the use of a proper surgical instrument (i.e. Péan clamp) is advanced under direct vision into the abdomen.

Extraumbilical transperitoneal

Though transumbilical access is the most common site for LESS, extraumbilical incisions have been utilized, including flank, paramedian, Pfannenstiel, and suprapubic [8, 11, 21, 29, 34]. By off-setting the incision closer to the intended target organ, a more direct access to the surgical field is created, which may improve tissue retraction and instrument range of motion; however, the scar may be more visible outside the umbilicus.

Retroperitoneal

Retroperitoneal access is achieved with an open (Hasson) technique. A 1.5-cm transverse skin incision is made at or just below the tip of the 12th rib. The flank muscle fibers are separated with two S-retractors to visualize the anterior thoracolumbar fascia, which is incised to enter the retroperitoneal space with the tip of the index finger. Digital dissection is performed along the anterior surface of the psoas muscle and fascia, posterior to Gerota's fascia (to create a space for the balloon dilator). A PDB balloon dilator (US Surgical, Norwalk, CT, USA) is inserted into the retroperitoneum and approximately 600 mL of air is instilled in the balloon to create the retroperitoneal space. This maneuver ensures that the peritoneal deflection is mobilized medially. In this manner, the *en bloc* kidney and surrounding Gerota's fascia are mobilized medially, thus exposing the posterior aspect of the renal hilum and the adjacent vessels to clear laparoscopic view. Once access has been gained, the single port of choice is utilized. Both the TriPort and the homemade single port have been successfully used in retroperitoneal LESS [24, 31].

Laparoscopic instrumentation

During LESS, instruments are placed in parallel, resulting in significant instrument clashing. To minimize clashing, specifically designed instruments have been created, including instruments that are prebent and ones that articulate. Additionally, improvement in available optics in the form of smaller diameter scopes, high-definition imaging, low-profile attached cameras, and deflectable scope tips significantly contribute to the wider acceptance of this surgical technique.

Prebent instruments

Prebent instruments (Olympus, Hamburg, Germany; Karl Storz, Tuttlingen, Germany) are designed to improve ergonomics and reduce external crowding of instrumentation around the access site (Figure 106.3A). Compared to standard laparoscopic instruments, they allow for the ability to triangulate and reduce internal and external clashing. When compared to flexible instrumentation in the laboratory setting, prebent instruments were less time-consuming and were found to have better maneuverability [35].

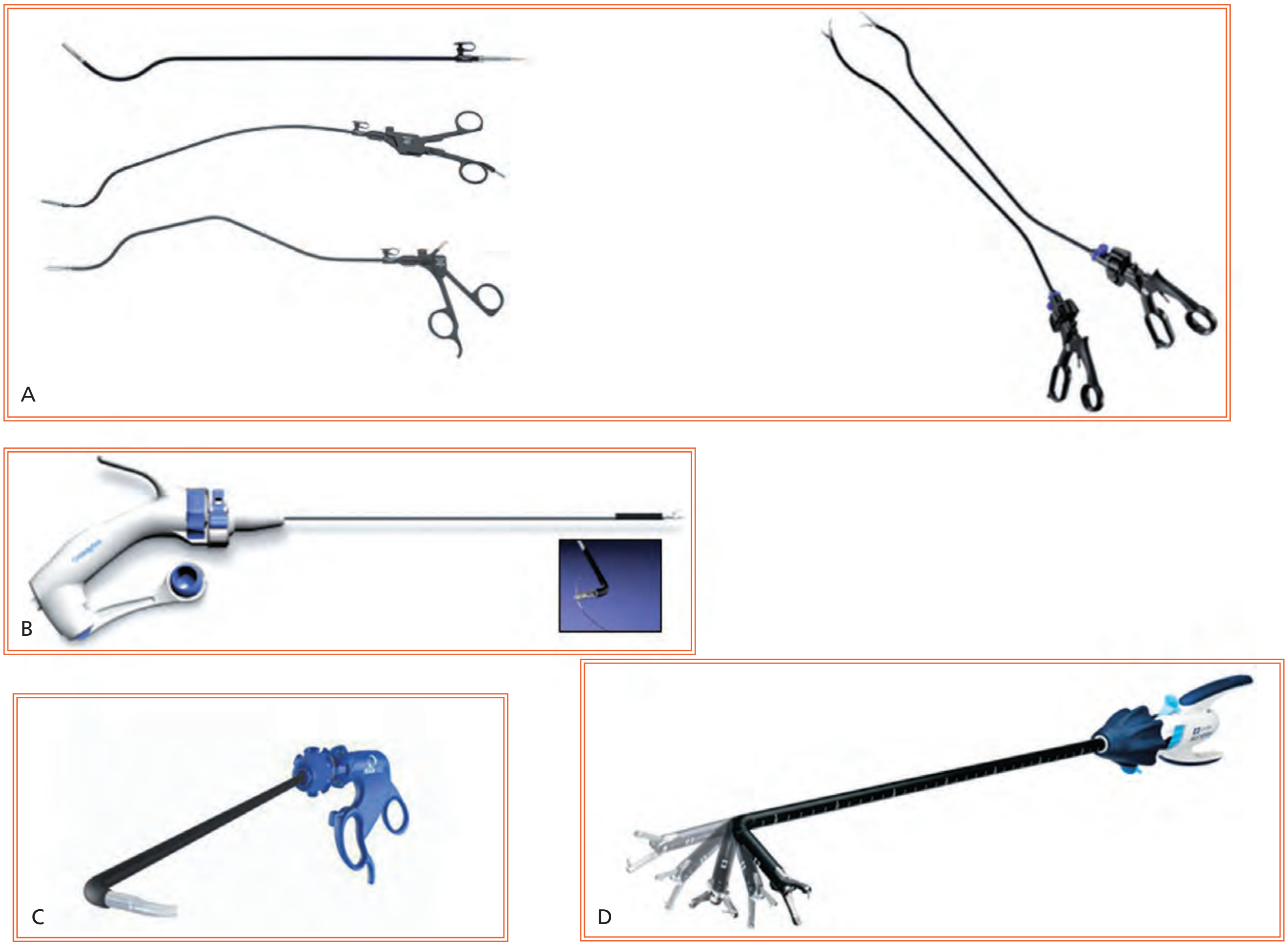

Figure 106.3 Commercially available laparoscopic instrumentation: (A) prebent instruments, (B) Autonomy Laparo-Angle, (C) Real Hand, (D) Roticulator.

Flexible instruments

Autonomy Laparo-Angle™

The Autonomy Laparo-Angle (Cambridge Endo, Framingham, MA, USA) series consists of Metzenbaum scissors, a Maryland dissector, monopolar hook cautery, and needle holders. The system allows for 7 degrees of freedom, full articulation, a tip that can rotate 360° around its axis, the capability of performing simultaneous actions such as articulating downward while rotating, and a handle that locks at any angle and rotates (Figure 106.3B).

Real Hand™

Real Hand instruments (Novare Surgical Systems, Cupertino, CA, USA) were designed with an EndoLink® mechanism which affords 7 degrees of freedom of movement. The full line of instruments includes a bipolar coagulator, various graspers, dissectors, and needle drivers. All have a locking mechanism, which allows for use as a straight or up to 90° angulated instrument (Figure 106.3C).

Roticulator™ articulating instruments

The Roticulator line of instruments (Covidien, Cupertino, CA, USA) include a grasper, shears, and dissector. The Roticulator offers 0–80° of articulation, 360° of rotation at all articulation angles, and spin-lock rotation position lock, and can perform as a fully rigid straight instrument and is 5 mm in diameter (Figure 106.3D).

Optics

Advances in the available optical systems in laparoscopy has greatly the facilitated the progression of LESS. From 5-mm lenses to articulating scopes, the field of fiberoptics is largely responsible for the re-emergence of LESS (Figure 106.4).

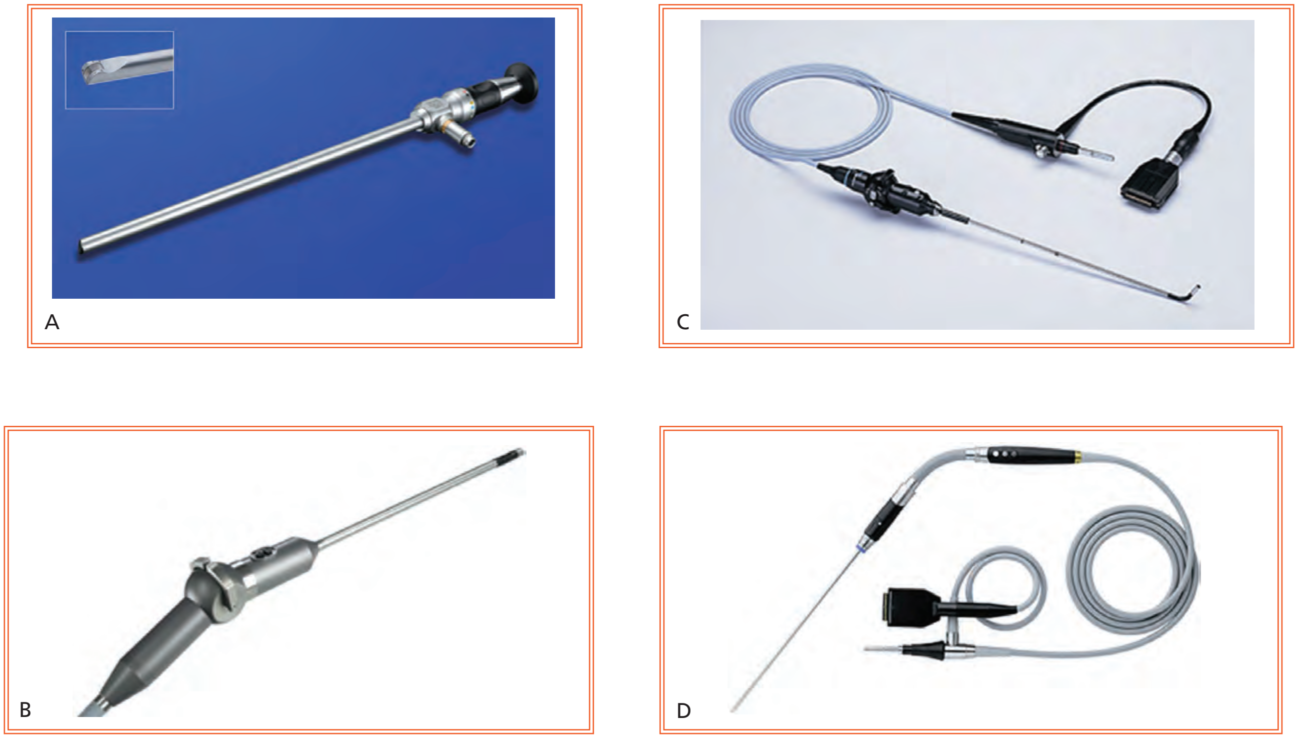

Figure 106.4 Laparoscopic optics. (A) Endochameleon, (B) IDEAL EYES (courtesy of Stryker), (C) EndoEYE LTF, (D) EndoEYE LS.

Endochalmeleon and extra-long HOPKINS®

The Endochameleon (Karl Storz, Tuttlingen, Germany) is a 10-mm laparoscope that allows the user to adjust the viewing direction between 0° and 120° as the surgical field requires. As a result, intraoperative telescope changes are often unnecessary, and the surgeon is able to optimally view the entire surgical field. The extra-long 5-mm HOPKINS endoscope (Karl Storz, Tuttlingen, Germany) has a working length of 50 cm to combat external collisions encountered during LESS (Figure 106.4A).

IDEAL EYES

The IDEAL EYES HD articulating 10-mm laparoscope (Stryker, Kalamazoo, MI, USA) includes distal flexible-tip technology to allow for 100° of flexion in all directions. This scope transmits both HD (1280 × 1024) and HDTV (720 pixels) video signals for optimal viewing in all areas of surgery. The IDEAL EYES is also available in a 5- and 10-mm non-HD format. The scope is 45 cm in length and was designed for bariatric surgery, but its length mean that external collisions are avoided during LESS (Figure 106.4B).

EndoEYE

EndoEYE technology (Olympus Surgical, Center Valley, PA, USA) integrates a distally mounted camera chip inside the laparoscope along with the light-guide cable to deliver a lightweight all-in-one system. Elimination of an externally mounted camera decreases external collisions. The rigid scopes are available in 5 and 10 mm versions with 0°, 30°, or 45° direction of views. The EndoEYE LTF includes all of the features of the previous mentioned laparoscopes with the addition of a flexible tip. A 100° field of view from multiple angles can capture the desired location head-on, from above, or even from behind. The flexible tip eliminates the need to change between 0° and 30° scopes intraoperatively (Figure 106.4C). The EndoEYE LS is a 5-mm 30° digital scope that allows the control section of the system to be bent by as much as 90°, further reducing the profile and limiting external instrument crowding (Figure 106.4D.).

Conclusions

LESS is developing at a rapid pace and as more surgeons adopt this laparoscopic approach, further refinement in technology will be identified. Although no perfect dedicated LESS ports exist, significant improvement in the LESS toolbox allows the LESS approach to spread significantly. Computer interface or robotic surgical instruments will better assist surgeons to further minimize access site morbidities.

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CHAPTER 107

Laparoendoscopic Single-Site Upper Tract Surgery

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Introduction

Since 1991, when the first laparoscopic nephrectomy was reported, laparoscopy has flourished in urology for the treatment of both benign and malignant conditions. Techniques and instrumentation have evolved to address more complex cases and pathology. New trocars, optics, instruments, and robotic devices have all been developed in a collective effort to improve efficacy, minimize patient morbidity, and reach for superior cosmetic results.

Laparoendoscopic single-site (LESS) surgery is one example of how new technology and new techniques have converged to allow for the performance of complex surgery through fewer incisions. In a short time span, nearly the entire gamut of urologic procedures has been performed via a LESS approach [1, 2]. Moreover, the diffusion of LESS has been fairly rapid across the globe. The goal of LESS surgery is to provide equivalent surgical outcomes with improved cosmetic results. Ongoing research is aimed at clarifying what, if any, perioperative or convalescence-related benefits may be offered by minimizing the number of incisions and cumulative incision length used compared to conventional laparoscopy [3].

Of the cases reported in the literature to date, the largest experience of urologic LESS surgery has been in the upper urinary tract, specifically renal procedures [1]. Upper tract urologic LESS surgery consists of both extirpative and reconstructive procedures of the kidneys, adrenal glands, and ureters. The anticipated surgical volume of LESS procedures for nearly all renal and adrenal pathology is expected to be intermediate or high in volume [4].

Although LESS surgery is a direct and natural extension of multiport, or "conventional," laparoscopy, there are several unique aspects to LESS. Access is most commonly through the umbilicus as the "single site," however, other locations can be utilized, such as a suprapubic or "mini-Pfannensteil" approach, a transabdominal or retroperitoneal flank approach, or even a Gibson incision–retroperitoneal approach [5–7]. Access can be via a specialized port, or clustered conventional ports, as discussed in Chapter 106. A wide variety of purpose-built instrumentation and various options for imaging (e.g. rigid vs flexible endoscopy) are available, and also discussed in Chapter 106. For each LESS operation, although modifications in technique and maneuvers are often made, conventional laparoscopic techniques are largely followed. As our overall experience with LESS surgery continues to grow and more urologists become familiar with the associated technology, we expect LESS to be adopted into everyday clinical practice of the future. It is certain that advances in technology and in particular robotics will allow single-site access to be commonplace with expanding indications and outcomes data to support its use. This chapter will discuss these interesting facets of urologic LESS surgery of the upper tract.

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Trocar/port-site placement

Umbilical and periumbilical

The majority of urologic upper tract LESS surgery is approached via an umbilical single-site access. Published reports of LESS have used all of the wide variety of access modalities available, both commercially manufactured and "homemade" designs created by surgeons using already available devices [1, 5, 8, 9] (Table 107.1) The umbilical trocar site is most often employed as it provides the opportunity to conceal incisions/scars. Mulitport trocars, GelPort™/GelPoint™ devices (Applied Medical, Rancho Santa Margarita, CA, USA), or a clustered series of low-profile trocars can be employed within the umbilicus. Multiport trocar placement at the umbilicus requires a single incision at the umbilicus, ranging from 2–5 cm to accommodate the chosen trocar (Figure 107.1). Use of separate low-profile trocars allows for more independent mobility and use of reusable devices, also using an incision ranging from 2–3 cm at the umbilicus (Figure 107.2).

Compared with conventional laparoscopy, during LESS surgery the laparoscope and working instruments

Table 107.1 LESS access modalities.

Device	Features
R-Port (Advanced Surgical Concepts, Dublin, Ireland)	
TriPort	Two 5-mm ports, one 12-mm port, one insufflation channel
	Incision required: 1.0–2.5 cm
	Disposable
QuadPort	Two configurations: (1) four 12-mm ports, one insufflation channel; (2) two 12-mm ports, one 5-mm port, and one 15-mm port, one insufflation channel
	Incision required: 2.5–60 cm
	Disposable
Uni-X (Pnavel Systems, Brooklyn, NY, USA)	Three 5-mm ports, one insufflation channel
	Incision required: 2 cm
	Disposable
UNO (Ethicon Endo-Surgery, Cincinnati, OH, USA)	Two 5-mm ports, one 15-mm port with 5-mm reducer cap
	Incision required: 1.5 cm
	Disposable
X-Cone (Storz, Tuttlingen, Germany)	Four 5-mm ports, one 5–13-mm port
	Incision required: 2.5–3 cm
	Reusable with up to 20 sterilizations
GelPort/GelPoint (Applied Medical, Rancho Santa Margarita, CA, USA)	Accepts multiple conventional trocars or direct insertion of instruments
	Incision required: 1.5–7 cm
	Disposable
SILS Access (Covidien, Hamilton HM FX, Bermuda)	Three foam insertion sites for passage of low-profile trocars
	Incision required: 2.5–3 cm
	Disposable
AirSeal (Surgiquest, Orange, CT, USA)	Uses recirculating CO_2 to create seal, may pass multiple instruments through ports of varying calibers
	Incision required: 1.5–2.5 cm
	Disposable

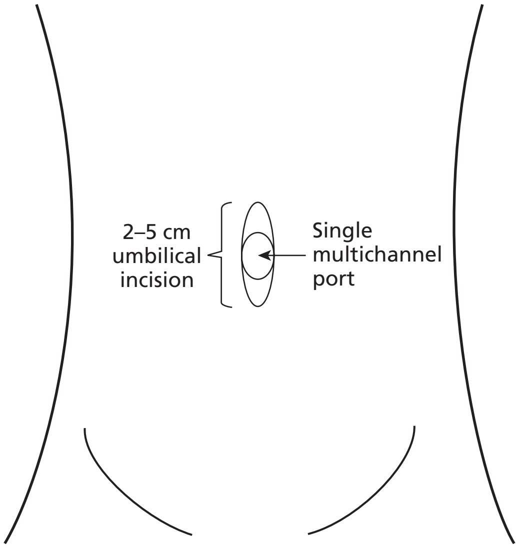
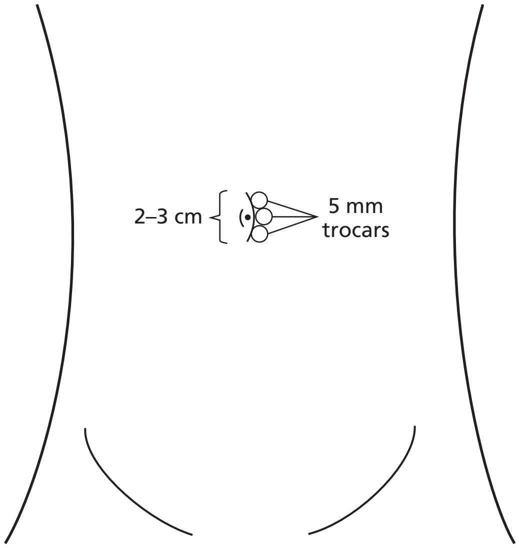


Figure 107.1 Insertion of a multiport trocar at the umbilicus.



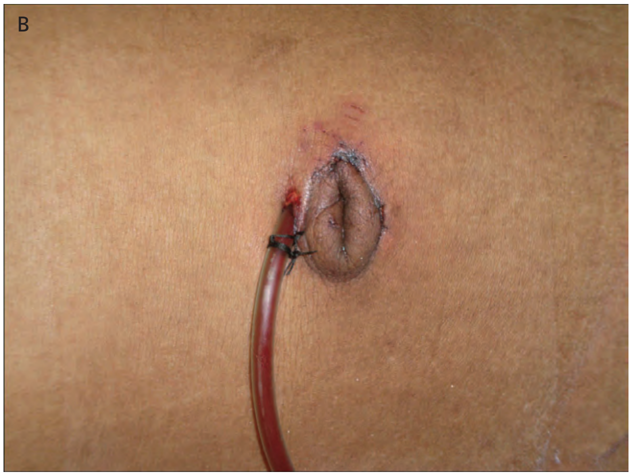


Figure 107.2 (A) Insertion of three 5-mm low-profile trocars through a small umbilical incision. (B) Postoperative scars demonstrating positioning and proximity of trocars to the umbilicus.

are in much closer proximity to one another due to the nature of single-site access. This can necessitate the use of flexible scopes and/or instruments to avoid clashing and to allow for triangulation. The umbilical port site allows for adequate access to the upper tract urologic organs with the use of regular length instrumentation, in most cases.

When treating obese patients, lateralization of the centrally located single incision may be warranted toward the side of intended surgery. The surgeon must consider whether this lateralized incision, no longer "hidden" within the umbilicus, still offers potential cosmetic advantages to the patient on a case-by-case basis. Alternatively, a retroperitoneoscopic LESS approach can be employed. Lateralization of the single site of access is akin to the lateralization of trocars employed during conventional laparoscopy in this patient population. Typically this maintains the midpoint of the incision at the craniocaudal level of the umbilicus, but simply shifts it laterally toward the targeted kidney or adrenal gland, providing improved visualization with the laparoscope and simpler reach with the working instruments. Considerations when employing this modification in trocar placement include: the risk of developing incisional hernias, anatomic approach to traversing versus splitting muscle layers, as well as postoperative pain and cosmesis.

Suprapubic or "mini-Pfannenstiel" approach

A suprapubic approach has been reported for LESS simple, radical, and donor nephrectomy, as well as LESS nephroureterectomy. In selected patients, a cosmetic advantage may be obtained by concealing the single incision below the waistline. A small, or "mini-Pfannenstiel," incision is employed that ranges between 5 and 8 cm in size. The size of the incision should allow for specimen extraction, but be as small as possible to optimize cosmesis. Access can be gained with either a multiport device (Figure 107.3) or using independently inserted, low-profile trocars [6, 10–12].

The suprapubic approach has more theoretical advantage in cases that require a sizable incision for specimen extraction, such as simple, radical or donor nephrectomy or nephroureterectomy, in contrast to purely reconstructive surgery (e.g. LESS pyeloplasty) or surgery requiring extraction of small specimens (e.g. LESS cyst decortication or LESS partial nephrectomy). To allow for

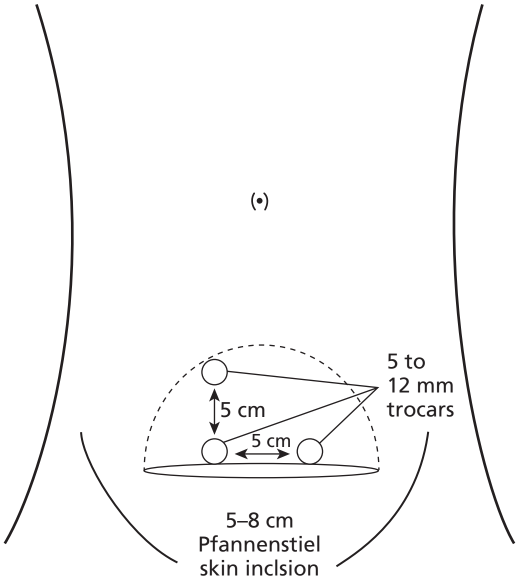


Figure 107.3 Insertion of three 5-mm low-profile trocars through a Pfannenstiel incision.

full access and ability to dissect circumferentially around the upper pole and posterolateral attachments of the kidney, it is useful to have bariatric and articulating laparoscopic instruments available.

Use of accessory and needlescopic trocars

Although even complex reconstructive LESS procedures, such as pyeloplasty and partial nephrectomy, can be performed with no accessory points of entry [6], the use of accessory trocars or 1.9-mm needlescopic instruments has been reported extensively in the early experience of LESS. These added instruments act as an adjunct to the single-site approach and provide for instrument triangulation and added retraction, or can assist with intracorporeal suturing and knot tying. Accessory ports create a bridge between conventional laparoscopy and LESS as surgeons learn LESS surgery, and play a critical role in challenging cases in which triangulation for adequate retraction and dissection is not adequately achieved with single-site access and available instrumentation.

With minimal to no morbidity, needlescopic instruments have been reported to enhance surgeon confidence and ensure patient safety during the diffusion of this new and challenging technique [4]. As experience with LESS increases and surgeons progress along the learning curve, the use of accessory trocars for assistance in triangulation and retraction will likely decrease. However, there will likely always remain an important role for accessory trocars or needlescopic instruments for more complex surgical cases. Moreover, additional access is always preferable to any compromise in safety or efficacy. Accessory trocars measuring from 5 to 12 mm in diameter have been reported. These are used by some urologists during LESS donor nephrectomy to allow for the expeditious and safe maneuvers necessary to limit the warm ischemia time of the renal allograft specimens. They also are adjuncts to LESS for complex reconstructive procedures or in patients with anatomic challenges requiring extensive adhesiolysis or body habitus limiting instrument flexibility. The site of accessory trocar placement can also be used as the location for drain placement at the culmination of the case.

Extirpative surgery

LESS nephrectomy

LESS nephrectomy can be performed for both “simple” nephrectomy and radical nephrectomy, for benign and malignant pathologies, respectively. Although done for differing indications, LESS nephrectomy has similar principles and maneuvers to conventional laparoscopic nephrectomy, with slight surgeon-specific modifications to overcome the novel challenges of the single-site approach of the operation [13].

The first laparoscopic extirpative surgery in urology was the laparoscopic nephrectomy reported in 1991, and this is now a relatively straightforward case often undertaken by new trainees prior to more complex renal surgeries [14]. Since the first LESS nephrectomy was reported in 2007 by Rane *et al.*, the number has soared and remains the most common LESS urologic surgery performed [15]. A simple nephrectomy for nononcologic indications allows for morcellation of the resection specimen. The most common location for trocar placement is at the umbilicus, and morcellation obviates the need to extend the umbilical trocar site incision, maximizing the cosmetic outcome [16]. However, extension of the incision is warranted in radical nephrectomies and nephroureterectomies to allow for passage of the entire kidney specimen intact for pathologic examination and appropriate staging without compromising the oncologic efficacy of the surgery.

Rane *et al.* described their initial experience with five LESS simple nephrectomies [16]. Their indications for simple nephrectomy included chronic reflux, recurrent infections, longstanding ureteropelvic junction obstruction, stone disease, and ureteral strictures, leading to poorly functioning symptomatic kidneys. In these cases of benign renal pathology, morcellation allows for an operative scar to be hidden within the anatomic folds of the umbilicus.

Since this report of LESS simple nephrectomies, other groups have reported LESS radical nephrectomy with adequate pathologic outcomes [5, 17, 18]. LESS radical nephrectomy has been reported through umbilical access as well as through a Pfannensteil incision. In both circumstances, the incision is commonly 4–8 cm in length for purposes of specimen extraction, unless morcellation is employed. Despite requiring a larger extraction site, LESS radical nephrectomy still requires fewer incisions compared to conventional laparoscopy, and the incision is at least partially hidden within the umbilicus or within the skin creases of the suprapubic region, depending upon approach utilized.

In a series comparing LESS simple and radical nephrectomy to conventional laparoscopic nephrectomy, Raman *et al.* reported equivalent operative time, postoperative analgesic use, length of hospitalization, and rate of complications; the LESS cohort was found to have a lower recorded estimated blood loss; however, the change in hemoglobin concentration across the two patient groups was not statistically significant [17]. More recently, a randomized controlled trial comparing LESS versus conventional multiport laparoscopic nephrectomy has demonstrated lower visual analog pain scores and decreased analgesic requirements for LESS surgery [19].

LESS partial nephrectomy

Partial nephrectomy remains a challenging operation even when performed by multiport laparoscopy. However, in selected patients, LESS partial nephrectomy has been demonstrated to be feasible and safe. LESS partial nephrectomy has been described without accessory trocars, technically replicating the conventional laparoscopic technique with careful hilar dissection for complete pedicle control, identification and excision of the tumor, and various hemostatic techniques coupled with the renorrhaphy (see Video 107.1) [5]. In efforts to minimize warm ischemia time and provide a hemostatic renorrhaphy, a 2-mm needlescopic accessory port is utilized by some experts for intracorporeal suturing [20]. As demonstrated by surgeons who have reported their experience with LESS partial nephrectomy, it is critical to convert to conventional laparoscopy in cases of limited exposure of the tumor resection site or when hemostasis is prohibitively challenging via a strict LESS approach.

Indications for conventional laparoscopic partial nephrectomy are expanding and now include resection of selected T1b tumors, central or hilar tumors, and multifocal tumors within the same kidney [21]. Currently, LESS surgery has been largely reserved for the strictest indications. In the renal LESS series reported to date, LESS partial nephrectomy was performed in a highly select patient population with ideal body habitus, limited prior abdominal surgery, and favorable tumor size and location.

LESS nephroureterectomy

In addition to LESS radical and partial nephrectomy, LESS nephroureterectomy has been reported as an oncologic application of single-site surgery of the kidney. For the treatment of upper urinary tract transitional cell carcinoma, LESS nephroureterectomy has been reported by several centers [1, 5, 6]. As with conventional laparoscopy, both retroperitoneal and transperitoneal approaches have been described. Transperitoneal LESS nephroureterectomy has been reported via an umbilical as well as a Pfannenstiel single-site incision. Through a Pfannenstiel approach, after completion of laparoscopic mobilization and freeing of the kidney and ureter, a bladder cuff was performed in an open manner [6]. In reports of the retroperitoneal as well as umbilical approach to transperitoneal LESS nephroureterectomy, specimens were extracted through a separate Gibson incision measuring between 6 and 10 cm in length, through which a formal bladder cuff excision was also performed [5, 22]. This length of incision for management of the distal ureteral segment and intact specimen extraction was acknowledged in multiple published works as a contradiction to the goals of LESS to minimize total incisional length and associated pain and cosmetic concerns.

LESS donor nephrectomy

LESS donor nephrectomy has been pursued by advanced laparoscopists only after significant experience with LESS in other renal extirpative procedures. The technique described for LESS donor nephrectomy mimics the established methods of conventional laparoscopic living donor nephrectomy first described in 1995 [23]. Important modifications unique to the LESS approach for living donor nephrectomy include the use of articulating or prebent instruments to overcome the challenges of single-port access and extra-long or bariatric instrumentation for adequate reach to the kidney, especially the upper pole and lateral aspects. Also, when selecting the mode of access for LESS donor nephrectomy, it is imperative that the surgeon(s) considers the approach to graft extraction, as time is of the essence. With this in mind, the use of a multiport device that allows for extraction and rapid re-establishment of pneumoperitoneum may be preferable to clustered trocars.

Single-site donor series have been reported by several different transplant centers with advanced laparoscopists who were facile at performing laparoscopic living donor nephrectomy [12, 24]. In this population of healthy volunteer donors, who are often related to the transplant recipients, safety is of utmost concern. Hence, the surgeon should maintain a low threshold to convert to multiport, hand-assisted, or open surgery in cases with a difficult anatomic approach or allograft procurement [1].

However, it is in this same population of young, healthy volunteers that the provision of a cosmetically superior result may be most valued by the patient. The initial publications on this less invasive approach to renal allograft procurement describe efficacy and feasibility of LESS donor nephrectomy.

A single comparative study reporting a single-surgeon experience of six LESS cases matched to six conventional laparoscopic donor nephrectomies reported statistically comparable perioperative parameters, renal allograft characteristics, and postoperative pain [12]. Perioperative parameters evaluated and compared included operative time, warm ischemia time, estimated blood loss, and length of hospitalization. Postoperative pain was assessed by narcotic requirements and patient-reported scores on a visual analog pain scale. Notably, the median pain score reported at discharge in the cohort of LESS donor nephrectomy was zero on a 0–10 visual analog pain scale. None of the six LESS cases required conversion to conventional laparoscopy to complete the case safely, and all allograft specimens were adequate for successful transplantation and immediate function once implanted.

A matched-pairs comparison of LESS donor nephrectomy to conventional donor nephrectomy revealed a quicker convalescence in the patient cohort undergoing LESS donor nephrectomy [25]. Parameters improved by the LESS approach included time on oral analgesics, time off work, and time to "100% recovery," as noted by patient questionnaires. In this study, warm ischemia time was statistically significantly higher in the LESS cohort; however, allograft function was noted to be immediate and comparable across the two groups.

LESS adrenalectomy

The first conventional laparoscopic adrenalectomy was reported in 1992 [26]. Since then, laparoscopic adrenalectomy has been accepted as a feasible and safe minimally invasive option for the surgical treatment of various adrenal neoplasms [27]. For small to mid-size adrenal lesions, laparoscopic adrenalectomy has become standard practice not only for urologists but also general surgeons at some centers. Debate exists regarding the efficacy of laparoscopy for the treatment of known or suspected adrenal cortical carcinoma, particularly for larger masses.

One of the earliest reports of LESS adrenalectomy was of retroperitoneoscopic adrenalectomy via a 4.5-cm trocar without the use of insufflation [28]. In this report, 53 patients with adrenal tumors were treated successfully via this approach and one patient (1.9%) required conversion to open surgery secondary to excessive blood loss from an adrenal vein injury.

In a contemporary series, nine patients undergoing LESS adrenalectomy for benign adenoma were compared to 17 patients undergoing conventional laparoscopic adrenalectomy [29]. Patients were matched with regard to age, sex, surgical indications, and tumor size. Operative time, blood loss, and hospital stay were found to be equivalent. The LESS group demonstrated a shorter period of postoperative intravenous patient-controlled analgesia use.

Reconstructive surgery

LESS pyeloplasty

Pyeloplasty is the most common reconstructive upper tract urologic surgery performed. With the advent of laparoscopic pyeloplasty in 1993, there was a significant movement toward a minimally invasive approach to the otherwise large, muscle-traversing flank approach for open pyeloplasty, which was the former standard [30]. Since the development and diffusion of laparoscopic pyeloplasty by urologists, both dismembered and V–Y laparoscopic pyeloplasties have been performed in large series with reliable postoperative outcomes [31, 32].

As with living donor nephrectomy, patients undergoing pyeloplasty are often young and healthy, without malignant pathology, and cosmesis may be of greater concern to them. A cohort of LESS pyeloplasty patients demonstrated a younger mean and median age when compared to other LESS upper tract operations in a single institution experience of upper tract urologic LESS [5]. Heightened efforts to minimize the overall incision burden and subsequent appearance of cutaneous scars in this population seem appropriate. Ongoing research is aimed at further defining the quality of life and cosmetic advantages that LESS urologic surgery may provide.

LESS pyeloplasty can be performed with or without the use of accessory trocars [5]. All techniques and associated procedures can be performed via LESS, including dismembered pyeloplasty, V–Y pyeloplasty, pyeloscopy, and stone extraction. We advocate flexible cystoscopy and placement of a 7F, 28-cm double-pigtail ureteral catheter prior to commencing with the LESS portion of the procedure. Other surgeons advocate a smaller 6F stent to facilitate positioning of the scissor blade between the stent and ureteral wall, and thereby facilitating spatulation. Still other surgeons prefer an antegrade approach to stent placement during laparoscopy. Although we consider rigid straight laparoscopic instruments to be sufficient for nearly all LESS surgery, spatulation of the ureter may be facilitated by the use of articulating scissors in some cases.

Conventional laparoscopic salvage pyeloplasty has been reported with promising results [33, 34]. However, to date, LESS pyeloplasty is reserved for idealized patients undergoing primary pyeloplasty for congenital ureteropelvic junction obstruction. LESS pyeloplasty can be performed in the setting of a crossing vessel, as dismembered, transposed pyeloplasty can be performed effectively.

Short-term postoperative outcomes have been reported for LESS pyeloplasty and compared to historical controls undergoing conventional laparoscopic pyeloplasty. In a study reported by Raman *et al.*, LESS pyeloplasty resulted in comparable perioperative and functional outcomes [35]. All perioperative parameters were equivalent, except for operative time and estimated blood loss, which were found to be significantly lower in the LESS cohort of patients.

A multi-institutional study by Schwartz *et al.* showed LESS pyeloplasty to be a safe option with success rates equivalent to conventional laparoscopic pyeloplasty [36]. In this series, the only clear benefit noted in the period of short follow-up was that of minimized incision size and postoperative scar formation, although postoperative pain and analgesic requirements were not assessed.

Ablative surgery

LESS cryoablation

Cryoablation has been demonstrated as an oncologically effective means of providing focal ablation therapy for the treatment of small renal masses, maintaining a nephron-sparing result [37]. Both laparoscopic and percutaneous, image-guided approaches have been well-described for renal cryoablation. Benefits of the laparoscopic approach to renal cryoablation include direct visualization of probe placement, monitoring the ice-ball formation visually or with intraoperative ultrasonography, and the means to mobilize bowel or other adjacent structures safely away from the area of focal ablation [38]. Transperitoneal as well as retroperitoneoscopic entry have been reported, differentially used based primarily on the anatomic location of the renal mass being ablated.

The technique for LESS cryoablation, using both transperitoneal and retroperitoneal approaches, was first reported in a human series in 2008 [39]. Since this initial report, LESS cryoablation has been reported by a number of different institutions as part of larger urologic LESS series in the literature [1]. To date, the literature has demonstrated LESS cryoablation to be a successful approach with acceptable perioperative parameters when compared to conventional laparoscopy. In a small number of cases, there was conversion to conventional laparoscopy [39]. However, LESS cryoablation is at a very early stage of the learning curve of LESS surgery.

Renal cryoablation provides an ideal opportunity for LESS because there is no specimen necessitating an extraction site. Also, intracorporeal manipulation is limited to mobilization of adjacent organs and intraoperative imaging with ultrasonography, whilst other LESS renal surgeries require advanced intracorporeal suturing techniques or vascular clamping and manipulation that are more easily achieved with the triangulation provided by conventional multi-port laparoscopy.

LESS cyst ablation/decortication

Laparoscopic and LESS management of renal cysts provides minimally invasive access to either aspirate and sclerose the cyst cavity, ablate the lining, or decorticate symptomatic renal cysts. Decortication by excision of the cyst wall with luminal fulgration using either an argon beam coagulator or electrocautery provides the most durable long-term outcome based upon rates of recurrence [40, 41].

Series of LESS cyst decortication have been presented in larger LESS series encompassing multiple operative LESS cases [1, 22, 42]. LESS cyst decortication has been reported through periumbilical access providing a transperitoneal approach as well as a retroperitoneal approach through a multichannel access port placed in the flank. Operative techniques vary based upon the location of the renal cyst being targeted as well as the complexity of the dissection required to expose the cyst for decortication. A combination of standard laparoscopic and articulating laparoscopic instruments has been reported to aid in these LESS cases. Also, one report cited use of an operative laparoscope to further minimize the access ports required, allowing for successful retroperitoneal LESS cyst decortication [7].

Patients with large renal cysts, reported as large as 15 cm, have been safely and successfully managed with LESS surgery, with minimal intraoperative blood loss and discharge commonly on the first or second postoperative day [1, 7, 42]. The length of hospitalization is likely a result of the early learning curve of LESS surgery. As with laparoscopic renal cryoablation, conventional laparoscopic cyst decortication has been reported as an ambulatory operation in experienced centers [43]. In future, LESS surgery for such ablative procedures should be tested for its clinical durability but also should be compared to conventional laparoscopy for the period of postoperative convalescence, since conventional laparoscopy already provides such remarkable outcomes.

Future of LESS for upper tract urologic surgery

Dissemination of advances in surgical technique is dependent upon the realized value of the advance. Furthermore the technique must prove reproducible beyond selected centers of excellence. LESS has proven its versatility based upon the wide range of urologic operations for which it has been successfully employed as an extension of conventional laparoscopy. Furthermore, as experience with LESS augments in some centers, more novice surgeons, including residents and fellows enrolled in urology training programs, are being exposed to these new techniques within an apprenticeship model. Also, as skill centers are using inanimate box trainers and electronic simulators as an adjunct aide in laparoscopic training outside the operating room, new LESS training modules should be developed to augment the breadth of these simulator platforms.

As surgeons become more experienced with LESS, expand the indications for LESS, and diffuse the techniques throughout resident training programs and the community, the number of cases will inevitably increase. This will in turn provide valuable data to evaluate the comparative efficacy and potential benefits of LESS over conventional laparoscopy and direct the field appropriately.

Further research efforts are also underway to develop improved instrumentation and access platforms to facilitate LESS. Motorized articulating instruments and robotic platforms will become available that will help overcome the inherent challenges of single-site surgery. Published reports have described the use of the da Vinci Surgical System as an adjunct to LESS urologic techniques [8, 44]. Currently under investigation are magnetic anchors and intracorporeal robotic mechanisms with the goal to minimize the number and length of incisions, as well as to provide better triangulation in LESS cases [45].

In future, it is imperative that prospective studies focused on patient quality of life and postoperative satisfaction with cosmesis are pursued. Further study is also necessary to elucidate any potential benefits with respect to pain and convalescence.

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CHAPTER 108

Laparoendoscopic Single-Site Lower Tract Surgery

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Introduction

Laparoscopic and robotic surgery has been increasingly used to perform pelvic urologic procedures. As surgeons have become more experienced with complex laparoscopic procedures, efforts are ongoing to further reduce the morbidity and improve the cosmesis of conventional multiport laparoscopic surgery. Laparoendoscopic single-site (LESS) surgery is a recently christened variant of laparoscopic surgery that encompasses a group of closely related techniques that perform laparoscopic and robotic procedures through a single skin incision, typically concealed within the umbilicus. Since the initial LESS nephrectomy performed about 3 years ago [1, 2], there have been multiple reports demonstrating technical feasibility of LESS surgery in performing various urologic procedures. Initially used for relatively straightforward upper tract procedures, with growing experience and availability of purpose-specific instrumentation, the use of LESS surgery has been carefully extended to pelvic urologic procedures. This chapter reviews the various clinical applications of LESS in pelvic urologic surgery.

Instrumentation

Improvements and refinements in instrumentation and technology have contributed to the recent surge in LESS procedures across surgical specialties. These include custom-specific, single-access devices, articulating and bent instrumentation, deflecting tip optics, and needlescopic instrumentation (see Chapter 106). In the future innovative intracorporeal instruments and custom-specific robotic platforms are likely to further enhance the scope and application of LESS surgery.

Clinical pelvic applications

After its successful use for upper tract surgery, various authors have successfully performed pelvic surgery through a single incision (Table 108.1). The various LESS urologic pelvic procedures include radical prostatectomy, radical cystectomy, benign prostatic hyperplasia (BPH) enucleation, and sacrocolpopexy.

Radical prostatectomy

Several authors have successfully performed LESS radical prostatectomy. Kaouk *et al*. reported LESS radical prostatectomy in four patients with prostate cancer. Selection criteria were stringent and included early (T1c) prostate cancer, body mass index (BMI) of 35 or less, and absence of prior pelvic surgery [3]. All procedures were performed using a multichannel single-port device inserted transumbilically without the need of any ancillary extraumbilical ports. The vesicourethral anastomosis was performed using free-hand laparoscopic suturing. The mean operative time was 3.25 h for the prostatectomy and 1.1 h for the anastomosis, estimated blood loss (EBL) was 288 mL, duration of hospitalization was 2.4 days, and duration of catheterization was 2 weeks. One patient developed a rectourethral

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Table 108.1 Laparoendoscopic single-site surgery (LESS): pelvic applications in urology.

Study	LESS procedure	Number of patients	Operative time (h)	Number of complications	Comments
Kaouk *et al*. [3]	Radical prostatectomy	4	4.4	1 rectourethral fistula	No extraumbilical ports Two patients had positive margins Three patients were continent Four patients had undetectable PSA at 1 month
Barrett *et al*. [4]	Radical prostatectomy	1	2.5	0	Used the da Vinci Si System Used one extraumbilical 5-mm port Negative surgical margins Functional results not reported
Rebenalt *et al*. [5]	Radical prostatectomy	1	4.9	0	Extraperitoneal laparoscopic approach
Desai *et al*. [7]	Simple prostatectomy	34	2	8	Procedure performed laparoscopically/robotically One mortality in a Jehovah's Witness All 33 remaining patients had improved IPSS and Qmax
White *et al*. [9]	Sacrocolpopexy	10	2.5	0	Technically feasible in all 10 cases Outcomes comparable to robotic and conventional laparoscopic sacrocolpopexy on retrospective comparison
Kaouk *et al*. [8]	Radical cystectomy	3	5.25	0	No extraumbilical ports Diversion performed extracorporeally Mean lymph node yield 16 No recurrence with at least 2 years follow-up

PSA, prostate-specific antigen; IPSS, international prostate symptom score.

fistula and two had positive surgical margins. Three patients used 0–1 pads and prostate-specific antigen (PSA) was undetectable in all patients at 1-month follow-up. Barrett *et al*. performed laparoscopic and robot-assisted radical prostatectomy in the human cadaver and subsequently extended robotic LESS to perform a procedure clinically [4]. The procedure was performed by placing three robotic ports (da Vinci Si; Intuitive Surgical, Sunnyvale, CA, USA) positioned through a 3-cm skin incision. The authors employed an additional 5-mm extraumbilical port through which a drainage tube was exited at the conclusion of the procedure. Rabenalt *et al*. reported the first clinical experience with a LESS extraperitoneal radical prostatectomy. A 2-cm midline infraumbilical incision was made and the preperitoneal space was developed using a balloon dilator. The Triport (Olympus Medical, Tokyo, Japan) was inserted through the incision to create an air-tight seal to the extraperitoneal space. Using straight, as well as prebent instruments, the procedure was completed successfully with an operative time of 290 min and an EBL of 100 mL [5].

Simple prostatectomy

LESS techniques have been successfully used to enucleate large volume adenoma in patients with symptomatic BPH. Sotelo *et al*. initially performed a LESS adenomectomy using the transperitoneal approach with a single-port device inserted in the umbilicus [6]. The bladder was dissected to enter the space of Retzius and the adenomectomy performed after making a transverse incision through the anterior bladder wall just proximal to the bladder neck. Desai *et al*. performed BPH enucleation using the transvesical approach (STEP procedure) in 34 patients with large-volume BPH. Mean age was 69 years, BMI was 26 kg/m^2, and American Society of Anesthesiology class was 2 [7]. The mean prostate volume estimated by transrectal ultrasonography was 102.5 mL and the mean baseline PSA level was

6.7 ng/mL. A novel single-port device was inserted percutaneously into the bladder through a 2–3-cm incision in the suprapubic skin crease. After establishing pneumovesicum, the prostate adenoma was enucleated transvesically using standard laparoscopic instruments, and the adenoma was extracted in pieces through the port. Digital assistance expedited enucleation of the apical adenoma in 19 (55%) cases. Transvesical enucleation was completed in all 34 cases; the mean operative time was 116 min, and the EBL was 460 mL. There was one death from postoperative bleeding from uncontrolled coagulopathy in a Jehovah's Witness who refused a transfusion of blood and blood products. There were three complications during STEP (one death, one bowel injury, and one hemorrhage) and five afterwards (four bleeding, one epididymo-orchitis). Open conversion was necessary in two patients for complications, and extension of the skin incision by 1–2 cm was necessary in two to expedite apical digital enucleation. The mean hospital stay was 3 days and mean analog pain score at discharge was 2. All 33 patients (excluding the patient who died) were voiding spontaneously at a maximum follow-up of 8 months, with a mean American Urological Association symptom score of 3, a maximum urinary flow rate of 44 mL/s, and a postvoid residual of 30 mL at the latest follow-up. No patient developed urinary incontinence. STEP is an effective treatment option for selected patients with large-volume obstructive BPH. Under pneumovesicum using laparoscopic visualization, the entire adenoma can be effectively enucleated and expeditiously extracted through the novel single port. Comparison of the STEP procedure with other open and transurethral techniques will determine its place in the surgical treatment of large-volume BPH.

Cystectomy

Kaouk *et al*. recently presented the technical feasibility of LESS radical cystectomy in two male and one female patients with muscle invasive bladder cancer [8]. All three procedures were successfully completed via a single transumbilical access. Mean operative time was 315 min, blood loss was 217 mL, and hospital stay was 6 days. Urinary diversion was performed extracorporeally by minimal extension of the umbilical incision. Pelvic lymph node dissection was performed up to the aortic bifurcation with a mean lymph node yield of 16. Pathologic evaluation revealed negative surgical margins and there was no recurrence with a minimum follow-up of 2 years. Despite this encouraging initial experience, urothelial cancer is a potentially lethal disease and oncologic factors are likely to outweigh cosmetic issues in management decisions. As such, more data are necessary before LESS techniques are used more frequently for muscle invasive bladder cancer.

Sacrocolpopexy

Laparoscopic and more recently robotic sacrocolpopexy have been performed as an alternative to open surgery for treatment of female pelvic organ prolapse. White *et al*. recently reported their experience in 10 patients undergoing LESS sacrocolpopexy for pelvic organ prolapse [9]. The procedures were performed exclusively using a single-port device inserted transumbilically through a 1.8-cm incision. Two strips of polypropylene mesh were inserted paravaginally through 1-cm incisions just lateral to the labia majora. The mesh was affixed to the vaginal apex and then to the sacral promontory with appropriate tension using intracorporeal suturing performed through the single-port device. The authors retrospectively compared their experience with patients undergoing laparoscopic (n = 10) or robotic (n = 10) sacrocolpopexy. The LESS approach was equivalent to the laparoscopic and robotic approaches in terms of operative time (160 vs 151 vs 150 min, respectively), EBL (48 vs 65 vs 87 mL, respectively), length of hospitalization (1.5 vs 1.6 vs 1.6 days, respectively), and pain levels as measured on a visual analog scale (0.7 vs 2.1 vs 1.4, respectively). All 27 patients who were available for 3- and 6-month follow-up reported adequate symptomatic relief and reduction of the pelvic organ prolapse on repeat assessment, attesting to the short-term equivalence in efficacy of the LESS approach compared to the laparoscopic or robotic approach.

Miscellaneous procedures

Various other LESS pelvic procedures have been anecdotally reported in the urologic literature. These include varicocelectomy [10], ureteral reimplantation [10–12], and vesicovaginal fistula repair (P. Rao, unpublished study). Small numbers and limited outcome data significantly limit the widespread use of these procedures using LESS techniques.

Conclusions

The recent application of LESS surgery in urology has been extended to select pelvic procedures. Generally, the number of procedures performed and outcome data for pelvic LESS surgery are scant compared to upper tract procedures. Increasing experience and potentially availability of an effective and dedicated robotic platform may facilitate more widespread dissemination of urologic pelvic LESS surgery.

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SECTION 7

Image-Guided Diagnostics and Therapeutics

CHAPTER 109

Radiologic Diagnosis of Renal Masses

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Introduction

Over that last 25 years, the evaluation of renal masses has been revolutionized by technical advances in ultrasound, multidetector computed tomography (MDCT), and magnetic resonance imaging (MRI) [1–4]. It is estimated that 50% of people over the age of 50 years have at least one renal mass that can be detected on cross-sectional imaging [5–7]. Most of these lesions are benign simple cysts that can be diagnosed with confidence and require no further evaluation or treatment [8]. However, most renal neoplasms are now found incidentally while evaluating the patient for other suspected pathology [1]. The role of the radiologist is not only to detect these renal lesions, but also to distinguish between benign and malignant masses, and to help direct the management of these lesions.

Over the past decade, the treatment of renal masses has become increasingly individualized with therapeutic options, including radical nephrectomy, laparoscopic nephron-sparing surgery, and laparoscopic or imaging-guided cryotherapy and radiofrequency ablation [9–14]. This chapter reviews the role of CT, MRI, and ultrasound in guiding the increasingly sophisticated process of characterizing and managing renal masses. Guidelines concerning the most efficacious use of the various imaging modalities with a view towards optimizing patient management are presented.

Imaging techniques

Multidetector computed tomography

Recent improvements in MDCT technology allow thinner collimation and faster scanning that provides multiphasic, high-resolution images of the kidneys. These hardware developments coupled with advances in three-dimensional (3D) imaging software and the availability of cheaper data storage capacity have provided new opportunities for imaging renal and urinary tract pathology. Isotropic imaging of the kidneys, ureters, and bladder is now possible, providing 2D multiplanar reformations (MPR), CT urography (CTU), and 3D imaging formats, with minimal artifacts, all derived from a single data acquisition [15, 16]. The kidneys can be scanned in less than 5 s, allowing for acquisition of thin-section images during the corticomedullary, nephrographic, and excretory phases. This multiphasic evaluation permits high-resolution imaging of not only the renal parenchyma but also the renal vasculature and collecting system.

Evaluation of a renal mass by CT requires a dedicated multiphasic CT protocol which may include the following scans: precontrast; arterial phase (15–25 s delay); corticomedullary phase (35–80 s delay); nephrographic phase (85–180 s delay); and excretory phase (>3 min delay). To reduce the patient radiation dose, the precontrast,

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nephrographic phase, and excretory phase scans are the ones most commonly obtained [15–17].

Noncontrast scans of the kidneys are performed initially to evaluate for the presence of fat or calcification in the mass and to detect nephrolithiasis. This scan also provides a baseline from which to quantify lesion enhancement on postcontrast scans. The scans performed during the arterial or corticomedullary phase, while limited for mass visualization, nicely display the renal vasculature, which is critical for surgical planning, particularly when partial nephrectomy is being considered. Arterial phase scans best show small hypervascular neoplasms and the renal arteries. The nephrographic phase optimizes mass visualization. The delayed phase scans are helpful in assessing the relationship of the renal mass to the renal collecting system and also visualizing the remainder of the urinary tract. The data from these various series can then be reconstructed at thinner intervals and transferred to a workstation where multiplanar reformatted images, maximum intensity projection (MIP) images, and 3D volume-rendered images can all be created [15–17].

Contrast enhancement and subsequent de-enhancement are characteristic features of renal malignancies. A renal lesion is considered to have enhanced when its density increases by more than 20 Hounsfield units (HU). If the density of the lesions increases by between 10 and 20 HU, it is considered indeterminate for enhancement and requires further testing. While these criteria seem straightforward, the accuracy of determining enhancement varies based on the type of CT scanner used as well as technical factors, including the kilovoltage and amperage of the X-ray beam, pixel size, image noise, slice thickness, beam hardening artifacts, and artifacts related to large body habitus. The size of the lesion is also important because volume averaging commonly occurs in lesions smaller than 10 mm in size.

Pseudoenhancement occurs when a cyst, usually of less than 2 cm, appears to artifactually enhance because it is surrounded by strongly enhancing parenchyma. This typically occurs during peak renal enhancement and should be suspected when a lesion is homogeneous and measures less than 10 HU on an unenhanced CT scan [18–21].

Rising healthcare costs and increasing radiation doses from MDCT have given rise to concerns about over- and inappropriate use of CT in modern medical practice. Using data from the Hiroshima and Nagasaki atomic explosions, radiation scientists and physicists have suggested that the linear nonthreshold theory for radiation-induced carcinogenesis is valid also at the low radiation doses associated with CT scanning, contending that MDCT will contribute to a greater incidence of cancer in the future. Others disagree over the applicability of such data to CT scanning, emphasizing that whereas the data from atomic explosions reflect a single exposure, patients are exposed to effects of cumulative radiation doses from repeat or follow-up CT scanning. They also contend that the biologic response to particulate exposure from the former atomic explosions may not be similar to the response to X-ray exposure from CT scanning [22].

Recently, all MDCT vendors have seen the importance of radiation dose reduction and have placed extensive effort into optimizing the dose while maintaining and improving applications of their systems. Better detector configurations, scanner speed, automatic exposure control techniques, prepatient X-ray beam collimation, noise-reduction filters, and prepatient bowtie and other physical X-ray beam filters have been implemented to reduce the radiation dose [22].

There are three major factors that potentially contribute to the delivery of high radiation doses from MDCT evaluation of the urinary tract: the replacement of conventional radiography with CT for the evaluation of stone disease and hematuria; the need for multiple follow-up CT studies; and the use of multiphase MDCT protocols [22].

Patients with nephrolithiasis are at a greater risk of having follow-up CT studies, leading to potentially high cumulative effective doses. The mean effective dose for a single-stone protocol study using MDCT is approximately 8.5 mSv. Even higher radiation doses are associated with CTU than with stone protocol CT, because scan protocols use up to four phases: noncontrast, corticomedullary, nephrographic, and excretory. If all scan parameters are kept identical, a four-phase MDCT exam exposes patients to a fourfold higher radiation dose (34 mSv). CT scanning for evaluation of renal masses, hematuria, and renal donors usually is performed using multiphase protocols, increasing the radiation dose substantially. In patients with renal cell carcinoma (RCC) and transitional cell carcinoma (TCC) who will have multiple follow-up examinations, MRI and magnetic resonance urography (MRU) should be considered as an alternative to multiphase MDCT as a means of reducing radiation dose to the patient [22].

Magnetic resonance imaging

Significant advances in MRI hardware and software with routine use of phased-array coils and parallel imaging permit fast and high spatial resolution imaging of the kidneys. Short breath-hold scans can produce superb multiphase renal images without significant peristaltic or respiratory motion artifacts [23–26]. The following imaging sequences should be obtained when evaluating a renal mass with MRI:

- Coronal T2-weighted single-shot turbo spin-echo sequence to serve as a localizing scan;

- Axial T2-weighted gradient and spin-echo sequence with fat suppression to search for renal mass invasion of the adjacent fat; a dual-echo axial T1-weighted gradient-echo sequence with in- and opposed-phase images to search for fat within the tumor;
- Axial T1-weighted fat-suppressed gradient-echo sequence for dynamic imaging using 20 mL of intravenous gadolinium with pre- and post-contrast images obtained during the arterial, corticomedullary, and nephrographic phases to assess tumor vascularity.

The physiologic principles behind the various dynamic postcontrast phases described in the MDCT section also hold true for dynamic MRI [27].

MRI is generally employed as a secondary imaging test when better characterization of a mass found on MDCT or ultrasound is needed. MRI is used as a primary imaging test in patients who have a severe allergy to iodinated contrast or who are pregnant. Because of the risk of nephrogenic systemic fibrosis, MRI with gadolonium should not be performed in patients with poor renal function. MRI may become more commonly employed for following renal lesions given the increased concerns regarding cumulative radiation dose. This is particularly applicable in young patients.

The chemical-specific tissue characterization capabilities of MRI are particularly helpful in characterizing certain types of renal lesion. Confident characterization of hemorrhagic cysts can be problematic on CT because the lack of enhancement of a small, dense renal mass may be difficult to confirm. Hemorrhagic cysts usually have high signal on T1-weighted MRI. The signal intensity of hemorrhagic or proteinaceous cysts on T2-weighted images is variable, ranging from a low to mildly increased signal compared with renal parenchyma, but usually a lower signal than seen in adjacent cerebrospinal fluid or other simple cysts. The combination of high signal on T1-weighted images and the lack of enhancement on MRI are diagnostic of a hemorrhagic renal cyst [23–27].

MRI is also useful in characterizing complex renal cysts. Septations within complex renal cysts that are vague on CT are readily depicted with MRI. Because fluid signal on T1-weighted images is usually darker than the low attenuation seen on CT, contrast enhancement within the septations is usually more apparent on MRI than on CT, especially with subtraction images [23–27]. MRI is more sensitive than CT in the detection of macroscopic fat within lesions such as angiomyolipomas (AMLs). While most AMLs can be characterized with CT, it may be difficult to obtain accurate CT density measurements on small lesions. MRI can confidently characterize AMLs in two ways. First, frequency-selective chemical fat suppression will result in subjective signal loss within fat-containing regions of the lesion. Secondly, chemical shift artifact will show a sharp, dark interface between the AML and normal renal parenchyma [23–27].

MRU is an exciting and evolving technique, which is clinically useful in the evaluation of patients with urinary tract obstruction, hematuria, surgically-altered anatomy, and congenital abnormalities, as well as in pregnant and pediatric patients or when ionizing radiation needs to be avoided. There are two major types of MRU techniques: static fluid MRU and excretory MRU. The first technique employs heavily T2-weighted sequences to image the urinary tract as a static collection of fluid. It works best in patients with obstructed and dilated collecting systems. In excretory MRU, intravenous gadolinium is administered and imaging is performed during the excretory phase of enhancement to better demonstrate nondilated renal collecting systems [24–27].

Ultrasound

Although CT is the premier imaging test in patients with suspected renal pathology, ultrasound is often the first imaging test ordered for renal evaluation. Despite its technical limitations, a large number of renal tumors can be correctly characterized sonographically. Recent advances in gray-scale and color-flow Doppler techniques, as well as tissue harmonics, have enhanced the ability of ultrasound to distinguish solid from cystic lesions, and to make the diagnosis of a simple renal cyst [28–31]. Sonography is employed on a daily basis for evaluating lesions detected incidentally on CT that are not clearly simple cysts.

Lesions which are felt to represent hyperdense cysts either contain hemorrhage or proteinacious fluid. Those containing proteinacious fluid are typically simple on ultrasound, whereas those containing blood can appear heterogeneous and partly solid.

Ultrasound is useful in evaluating complex cystic lesions and detecting septations or minimal mural nodularity. This technique, however, is operator dependent and can be extremely limited in obese patients or when there is a large amount of adjacent bowel gas. Sonography can be quite useful for assessing the presence of renal vein thrombus with 75% sensitivity and 96% specificity, and 100% accuracy for detecting thrombus in the inferior vena cava [30, 31]. Intraoperative ultrasound has become a useful tool in guiding the surgeon during nephron-sparing surgery of small renal cell neoplasms.

Positron emission tomography–computed tomography

Most malignancies exhibit increased metabolic activity leading to increased utilization of glucose. Positron emission tomography (PET) imaging exploits the fact that the glucose analog, F-18-2-fluoro-2-deoxy-glucose (FDG), shows increased intracellular accumulation in malignant tissue. PET–CT is a fixed combination of PET and CT scanners in a combined imaging system. The nearly simultaneous data acquisitions lead to minimization of spatial and temporal mismatches between modalities by eliminating the need to move the patient during the examination. The result is a fused image that provides biologic and anatomic information. Imaging metabolic information of tumor tissue often provides more sensitive and specific information concerning the extent of malignancy than anatomic information alone [32–35].

Although FDG-PET is a well accepted method for the detection and staging of a number of malignancies, including lung, breast, colorectal, and esophageal cancer, it currently has a limited role in evaluating RCC. Several studies have shown that FDG-PET has a high specificity, but its sensitivity is inferior to that of CT and MRI in the evaluation of suspicious primary or metastatic RCC. FDG-PET surpasses the 90% sensitivity mark only for lesions at least 2 cm in diameter [32, 33]. Although there are studies that report sensitivity of FDG-PET to be as high as 94%, it is generally accepted that malignancy cannot be ruled out with a negative study. RCCs have inconsistent FDG uptake, which may be due to hypo- or iso-metabolism relative to background tissues, lack of accessibility of FDG, or heterogeneity of glucose transporter expression [34, 35].

Renal mass characterization in the patient with renal insufficiency

The characterization of renal masses is problematic in patients with renal insufficiency as iodinated contrast is potentially nephrotoxic and intravenous gadolinium is associated with a small risk of nephrogenic systemic fibrosis. In most cases, sonography can characterize a Bosniak type I and II cyst. Noncontrast-enhanced MRI is also useful in confidently characterizing cysts. Neither modality will provide information about the vascularity and contrast enhancement of a renal lesion.

Diffusion-weighted imaging (DWI) is a noncontrast MRI technique that has shown great promise in the characterization of renal lesions. DWI measures the Brownian motion of water molecules in biologic tissues, which has been shown to be inversely proportional to cellular density, presumably because increased cellular density limits water diffusion in the interstitial space. The apparent diffusion coefficient (ADC), a quantitative parameter measured from DWI, has been shown to have the potential to differentiate benign and malignant masses [25, 33].

One preliminary study aimed at investigating the potential role of DWI in the characterization of renal tumors showed that renal lesions with different tissue contents may have different diffusion characteristics. Solid tumor tissue has lower ADC values than necrotic or cystic tumor tissue, whereas necrotic or cystic tumor tissue has lower ADC values than benign cysts. This distinction is important for differentiating benign cysts from extensively necrotic or cystic tumors that may demonstrate little or no contrast enhancement and an imaging appearance similar to a complex benign renal cystic lesion on conventional MRI [33].

DWI offers the potential to differentiate solid RCCs from oncocytomas and characterize the histologic subtypes of RCC. DWI might be a reasonable, albeit less accurate, alternative to contrast-enhanced MRI for renal mass characterization in patients with contraindications to gadolinium-based contrast [25, 33].

Cystic renal masses

Incidentally discovered renal cysts are commonly found on cross-sectional imaging studies. Strict imaging criteria were developed by Bosniak in 1986 [36] to categorize renal cysts as benign, malignant or indeterminate (Table 109.1), and to guide the management of these lesions. The Bosniak classification has since undergone several modifications [37–40]. Although initially described for lesions found on CT, the criteria can be applied to MRI with overall similar accuracy [41]. In some cases, MRI may depict additional septae, thickening of the wall or

Table 109.1 Bosniak classification of cystic renal masses.

Category	Features
I	A simple water-attenuation cyst with a hairline-thin wall, without septa, calcification, or solid components; no contrast enhancement
II	Bosniak type I with a few thin septa or fine calcifications in the wall or septa
	Sharply marginated, nonenhancing, uniformly high-attenuation lesions of <3 cm
IIF	Bosniak type II cystic lesion with minimal enhancement of a hairline-thin septum or wall, or minimal thickening of the septum or wall; the cyst might contain calcification that might be nodular and thick, but there is no contrast enhancement
	Uniformly high-attenuation lesions of >3 cm
III	Bosniak type IIF cystic lesion with thickened irregular walls or septa, and contrast enhancement
IV	Enhancing soft tissue components or mural nodules

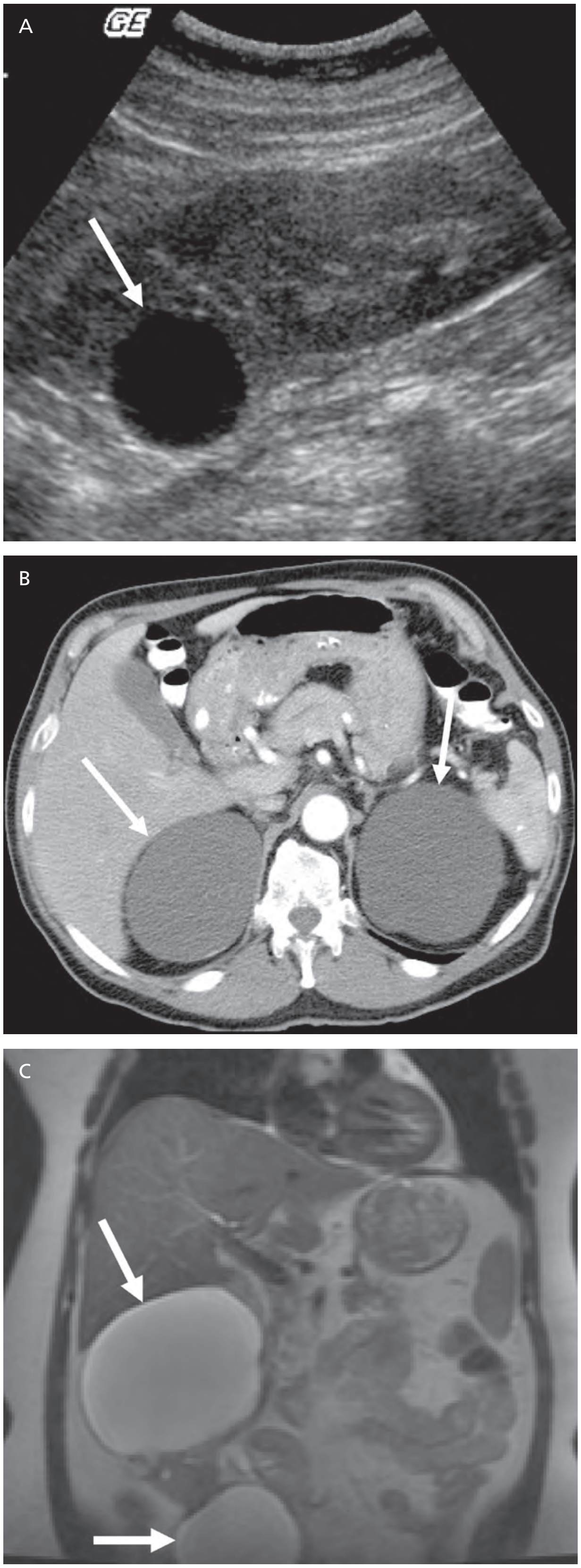

Figure 109.1 Bosniak type I renal cyst. (A) Longitudinal sonogram shows a well-marginated, anechoic cyst (arrow) along the posterior aspect of the upper pole of the right kidney. (B) Axial contrast-enhanced CT scan shows large, bilateral, nonenhancing water density renal cysts (arrows). (C) Coronal T2-weighted MR image shows well-marginated, hyperintense cysts (arrows) with paper-thin walls in the upper and lower poles of the right kidney. Note the absence of mural thickening or nodularity.

enhancement, which may lead to an upgraded Bosniak classification.

Category I lesions

These lesions are benign simple cysts requiring no further diagnostic imaging or follow-up (Figure 109.1). On CT, these lesions must have a paper-thin wall, entirely fluid attenuation measuring between 0 and 20 HU, and demonstrate no enhancement following the intravenous administration of contrast. These lesions do not contain septations or calcifications.

Category II lesions

These lesions are also benign, but are minimally complicated (Figure 109.2). They may contain a few paper-thin septations. They may also contain fine curvilinear, mural or septal calcification. This category also includes hyperattenuating cysts that measure less than 3 cm, and are round and sharply marginated, with at least one-quarter of the lesions extending outside the renal parenchyma. Most importantly, they must demonstrate uniform high attenuation and no enhancement with intravenous contrast. Cysts that measure between 20 and 40 HU are usually proteinacious cysts, and with a density of greater than 40–50 HU are likely to be hemorrhagic. The latter will appear complex on ultrasound. They may appear solid or semi-solid due to clot retraction and can be miscategorized by ultrasound.

In one study, Jonisch *et al.* attempted to differentiate high-attenuation renal cysts from RCCs on unenhanced CT scans [16]. They retrospectively evaluated the attenuation values and degree of uniformity/heterogeneity in 56 hyperdense renal cysts and 54 RCCs. The mean attenuation for hyperdense cysts was 53 HU and for RCCs was 38 HU, but there was significant overlap when evaluating attenuation values alone. However, when evaluating uniformity versus heterogeneity of the lesion, the authors concluded that a homogeneous, hyperattenuating renal masses with an attenuation of 70 HU or greater had a 99.9% likelihood of being a benign, high-attenuation renal cyst. Most RCCs in their study had attenuation values less than that of renal parenchyma

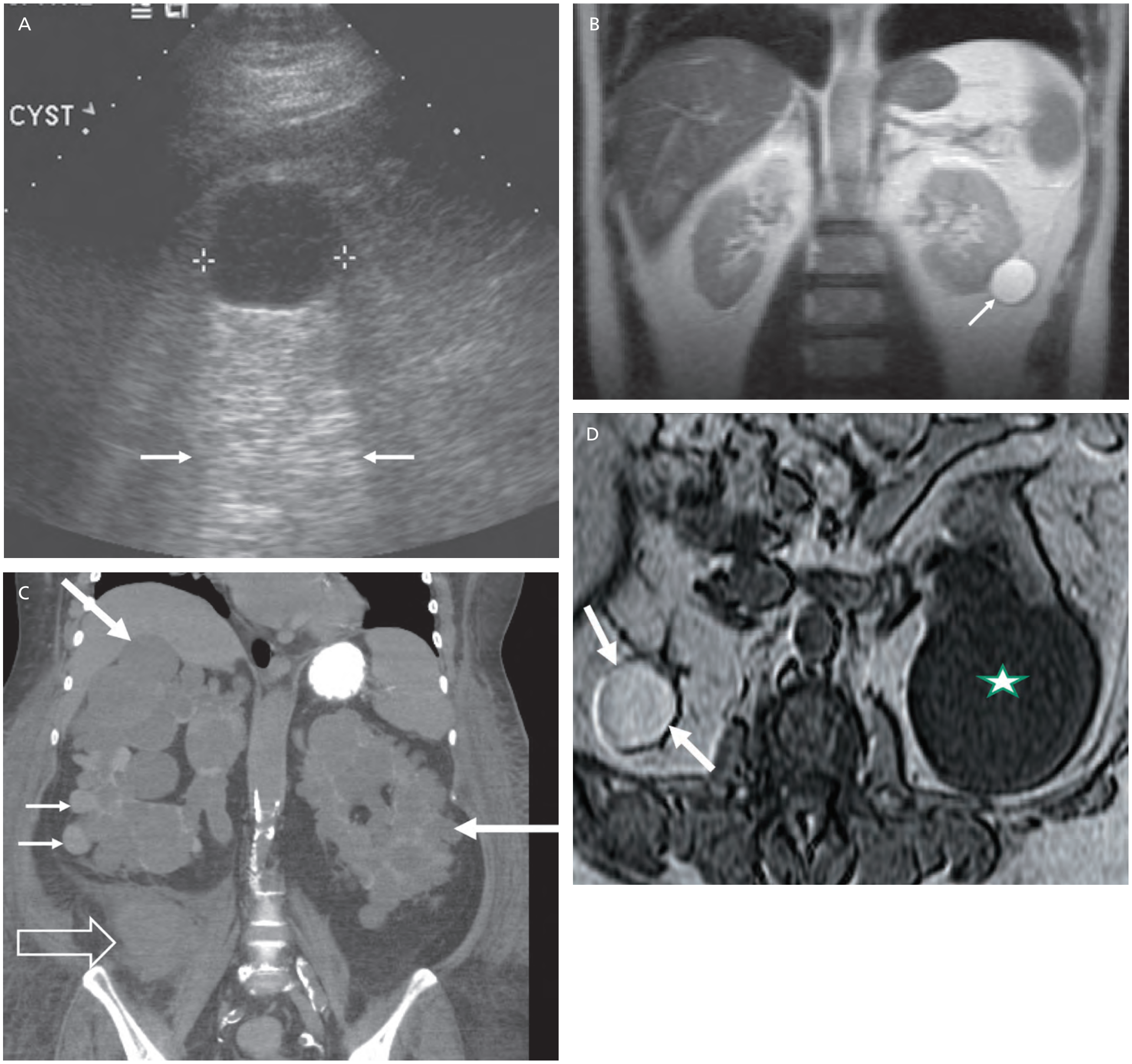

Figure 109.2 Bosniak type II renal cyst. (A) Transverse sonogram shows a well-marginated cystic structure (cursor) with fine, low level internal echoes. Note the acoustic enhancement (arrows) posterior to the cyst. (B) Coronal T1-weighted MR image shows a hyperintense cyst (arrow) indicating the presence of hemorrhage and/or mucin. (C) Coronal unenhanced CT scan in a patient with adult polycystic kidney disease demonstrates multiple simple (type I) (large solid arrows) and hyperdense (type II) (small solid arrows) renal cysts. The high attenuation within the cysts is due to hemorrhage. There is a renal transplant (open arrow) in the right iliac fossa with surrounding hemorrhage. (D) Axial T1-weighted image reveals a hyperintense hemorrhagic (type II) right renal cyst (solid arrows) and a hypointense left simple (type I) renal cyst (star).

(20–30 HU) and were often heterogeneous in attenuation. High attenuation renal cysts can in many cases be differentiated from RCC on unenhanced CT [16, 42, 43].

Category IIF lesions

These lesions are likely benign but require a period of observation or follow-up (the F stands for follow-up) to prove their benignity (Figure 109.3). These lesions may contain an increased number of septa or have minimal septal or mural thickening. Category IIF lesions may contain thick, irregular or nodular calcifications. When a high-attenuation lesion is completely intrarenal, the smoothness of its wall cannot be assessed. Accordingly, completely intrarenal high-attenuation lesions, as well as lesions greater than 3 cm in diameter, are included in this category. These lesions may also have a slightly indistinct interface with the adjacent renal parenchyma [34–38].

These lesions should be reimaged with CT or MRI in 6 months and then annually or every other year for 5 years. Stability over time suggests these lesions are benign, recognizing that some malignant lesions can grow slowly and that cysts can enlarge. Therefore, on follow-up imaging their morphologic characteristics must be evaluated in addition to their size. If there is any increase in the thickness or in the irregularity of the wall or septa, surgical exploration is indicated. MRI can be particularly useful in evaluating hemorrhagic cystic renal masses and for the presence of septal or mural enhancement. The introduction of the IIF category in 1993 has prevented unnecessary surgery in large numbers of patients [34–38].

Category III lesions

These are truly indeterminate lesions that cannot be diagnosed accurately as benign or malignant based on their imaging appearance. They contain thick walls or thick septa that demonstrate measurable enhancement (Figure 109.4). They may contain more extensive, thickened, and irregular calcifications. At pathology, these lesions are multilocular cysts, infected or hemorrhagic cysts, multilocular cystic nephromas, or cystic RCCs. The risk of malignancy in this group has been reported to range up to 59%. Since significant numbers of patients with Bosniak type III lesions undergo surgery for ultimately benign disease, some have advocated biopsy in this patient cohort [1, 4, 20].

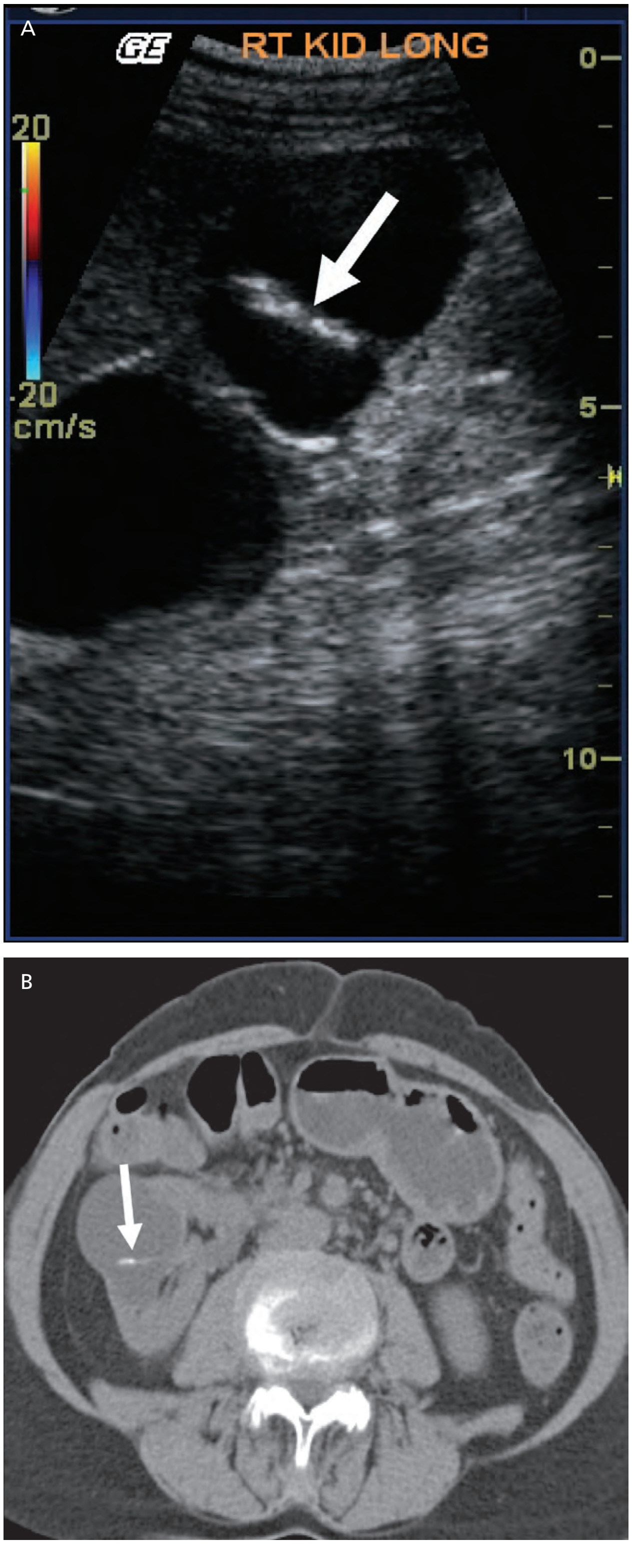

Figure 109.3 Bosniak type IIF renal cyst. (A) Longitudinal sonogram shows minimal thickening and calcification of a septation (arrow) in a patient with right renal cysts. (B) The calcification (arrow) is better appreciated on this transverse unenhanced CT scan. This lesion otherwise fulfills the imaging criteria for a simple cyst.

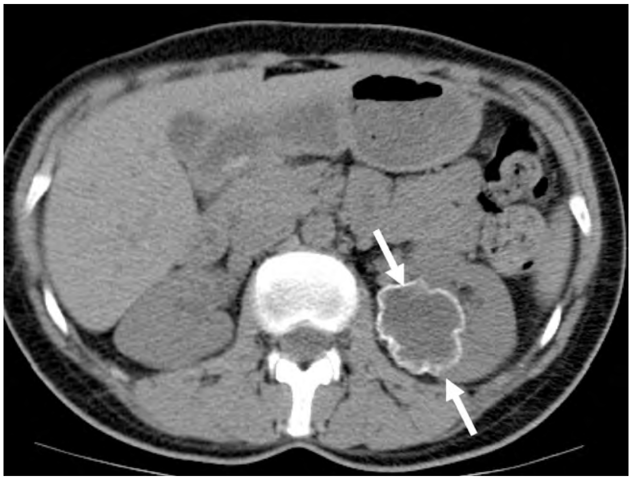

Figure 109.4 Bosniak type III cystic renal lesion. Axial unenhanced CT scan shows thick, irregular calcification (arrows) associated with a low-density renal mass. This lesion proved to be a renal cell carcinoma.

Category IV lesions

These lesions are clearly malignant and require surgical removal. They may have findings similar to category III lesions, but also have enhancing soft tissue components adjacent to the wall or septa (Figure 109.5). These lesions are usually cystic clear-cell carcinomas (accounting for 4–15% of all RCCs), multilocular cystic RCCs, cystic nephromas, and mixed epithelial and stromal tumors [36–39].

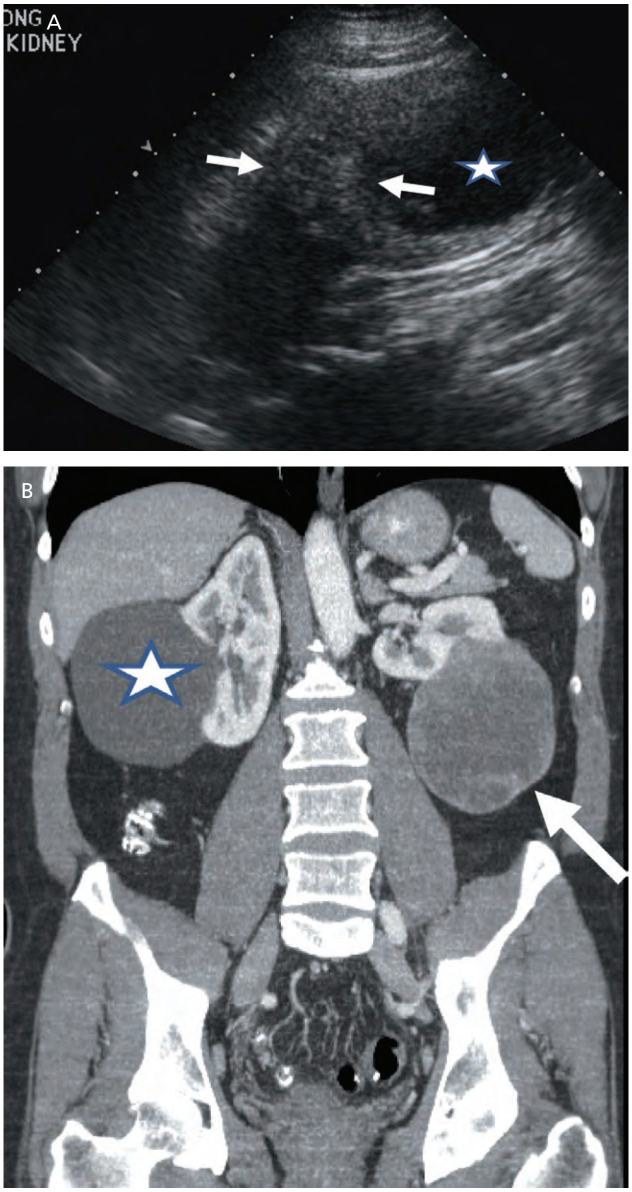

Figure 109.5 Bosniak type IV cystic renal lesion. (A) Longitudinal ultrasound of the left kidney shows a lower pole mass that has mural thickening superiorly (arrows) and a more cystic component inferiorly (star) (B) Coronal reformatted contrast-enhanced CT image shows mural and septal enhancement (arrow) of this mass. Note the Bosniak type I cyst at the lower pole of the right kidney (star).

Multilocular cystic nephromas

Multilocular cystic nephroma is a benign renal neoplasm that has a biphasic age and sex distribution. Two-thirds of multilocular cystic renal tumors occur in a predominately male pediatric population between the ages of 3 months and 2 years. Approximately one-third occur in a mostly female population, with a peak incidence in the fifth and sixth decades of life. Presenting symptoms depend on the age of the patient. Children typically present with a painless, progressively enlarging, palpable abdominal or flank mass that has a variable growth rate and may be discovered incidentally. Adults may have a variety of nonspecific signs and symptoms, including abdominal and flank pain, urinary tract infection, and hypertension. Microscopic or gross hematuria can occur in cysts in both adults and children. Variable degrees of obstruction of the renal collecting system can occur due to herniation of the tumor, which can lead to urinary tract infection.

Most adult patients are asymptomatic and these lesions are discovered incidentally. A complicated cystic lesion is typically identified on cross-sectional imaging (Figure 109.6) [36–39].

Benign solid renal masses

Most solid renal masses can be accurately characterized with cross-sectional imaging so that biopsy is not necessary [44, 45]. This is particularly true for AMLs (Figures 109.7 and 109.8) and RCCs, the two most common solid renal lesions in adults. Several pseudotumors can mimic solid renal lesions and must be excluded in order to avoid further evaluation or unnecessary surgery. Occasionally, a prominent column of Bertin, a dromedary hump, or persistent fetal renal lobulation can simulate a renal mass on ultrasound, but these can usually be correctly diagnosed with CT or MRI. These pseudolesions have a similar contrast-enhancement profile to normal renal parenchyma. In the case of persistent renal fetal lobulation, a normal renal pyramid is present within the center of the bulging portion of renal parenchyma.

Benign lesions that can simulate a renal neoplasm include focal acute pyelonephritis [46], renal abscess (Figure 109.9) [47], renal hematoma (Figure 109.10) [48, 49], focal xanthogranulomatous pyelonephritis (XPG) [50, 51], arteriovenous malformations (AVMs) (Figure 109.11) [52–54], and acute focal infarction (Figure 109.12). Extremely rare entities such as extramedullary renal hematopoiesis, tuberculoma related to therapy for bladder cancer, and splenorenal fusion can also mimic a renal mass.

Often the clinical history or additional findings on CT can be useful in making the correct diagnosis. For example, stranding in the adjacent perinephric fat

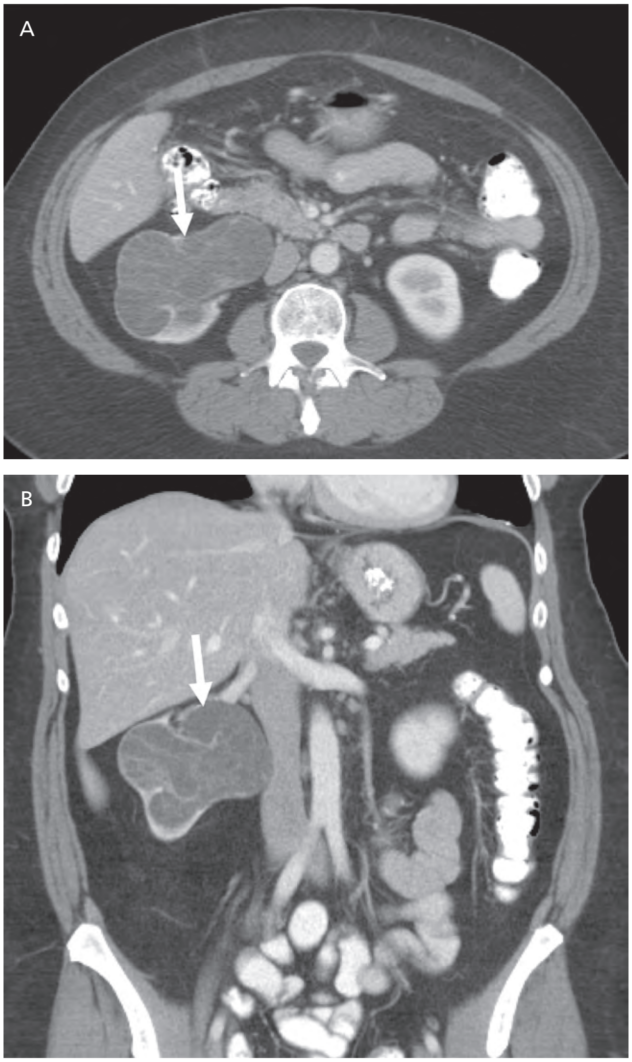

Figure 109.6 Multilocular cystic nephroma: CT features. (A) Axial and (B) coronal reformatted images disclose a multiseptated central cystic mass (arrows) involving the left renal pelvis.

should raise suspicion for acute pyelonephritis, although there are rare infiltrative renal tumors such as medullary RCC that can demonstrate this finding. In the case of focal pyelonephritis, there is a wedge-shaped area of heterogeneous hypoattenuation with no well-defined wall and no bulge on the renal surface, features that help distinguish it from RCC. If there is still a question about the nature of the mass, a follow-up scan showing healing and resolution can be helpful [46, 47].

AVMs can be intraparenchymal (see Figure 109.11) or in the renal sinus, but observing that the mass enhances to the same degree as the renal artery should be the clue to the correct diagnosis on CT and MRI. The feeding renal artery to the AVM is often enlarged as well. On gray-scale ultrasound an AVM appears as an anechoic structure that fills with color on color Doppler sonography. On noncontrast MRI scans, AVMs manifest as intralesional flow voids that show early enhancement, abnormal tortuous vessels, and an early draining vein following the intravenous administration of contrast [52–54].

Focal XGP can be difficult to distinguish from an RCC, but the presence of a staghorn calculus, which occurs in 70% of cases, is a helpful clue. There may be low attenuation within the associated collecting system mass due to the presence of lipid-laden macrophages. This disorder typically occurs in diabetic patients [50, 51].

When renal hematomas (see Figure 109.10) occur in the setting of trauma, the diagnosis is usually straightforward. However, renal hematomas can also occur spontaneously in patients who are anticoagulated, or have a coagulopathy or vasculitis. Typically, radiologists are not privy to this information to assist in the diagnosis. On noncontrast CT images, the hematoma may be hyperdense and there should be no contrast enhancement. Occasionally, active extravasation of contrast may be visualized. Hematomas are more easily diagnosed with MRI because of the typical signal characteristics of blood.

Subepithelial renal pelvic hematomas (Antopol–Goldman lesions) are a rare cause of a heterogeneously dense or hyperdense mass in the renal pelvis. They do not show contrast enhancement and may cause worrisome extrinsic compression on the renal collecting system. These lesions are often confused with renal pelvic malignancies, and in most cases, patients have undergone nephrectomy for what was thought to be malignant disease [1].

Angiomyolipomas

AMLs are the most common benign mesenchymal renal neoplasms and are comprised of fat, smooth muscle, and vascular tissue [55–58]. They typically occur sporadically in middle-aged patients, and are four times more common in females than males. Tuberous sclerosis, an autosomal dominant disease, accounts for 10–20% of all individuals with AML. The lesions in tuberous sclerosis are seen in younger patients and with equal frequency in males and females. The lesions in the sporadic form are usually less than 5 cm in diameter; however, AMLs seen in tuberous sclerosis can be much larger and are often multiple and bilateral [59]. Although benign, AMLs often increase in size over time and larger tumors have a propensity to bleed (see Figure 109.8). AMLs have a greater tendency to grow when they are multiple.

The imaging appearance varies according to the proportions of fat, muscle, and blood vessels. Since 95% of AMLs contain macroscopic fat (see Figures 109.7 and 109.8), the diagnosis can usually be made with

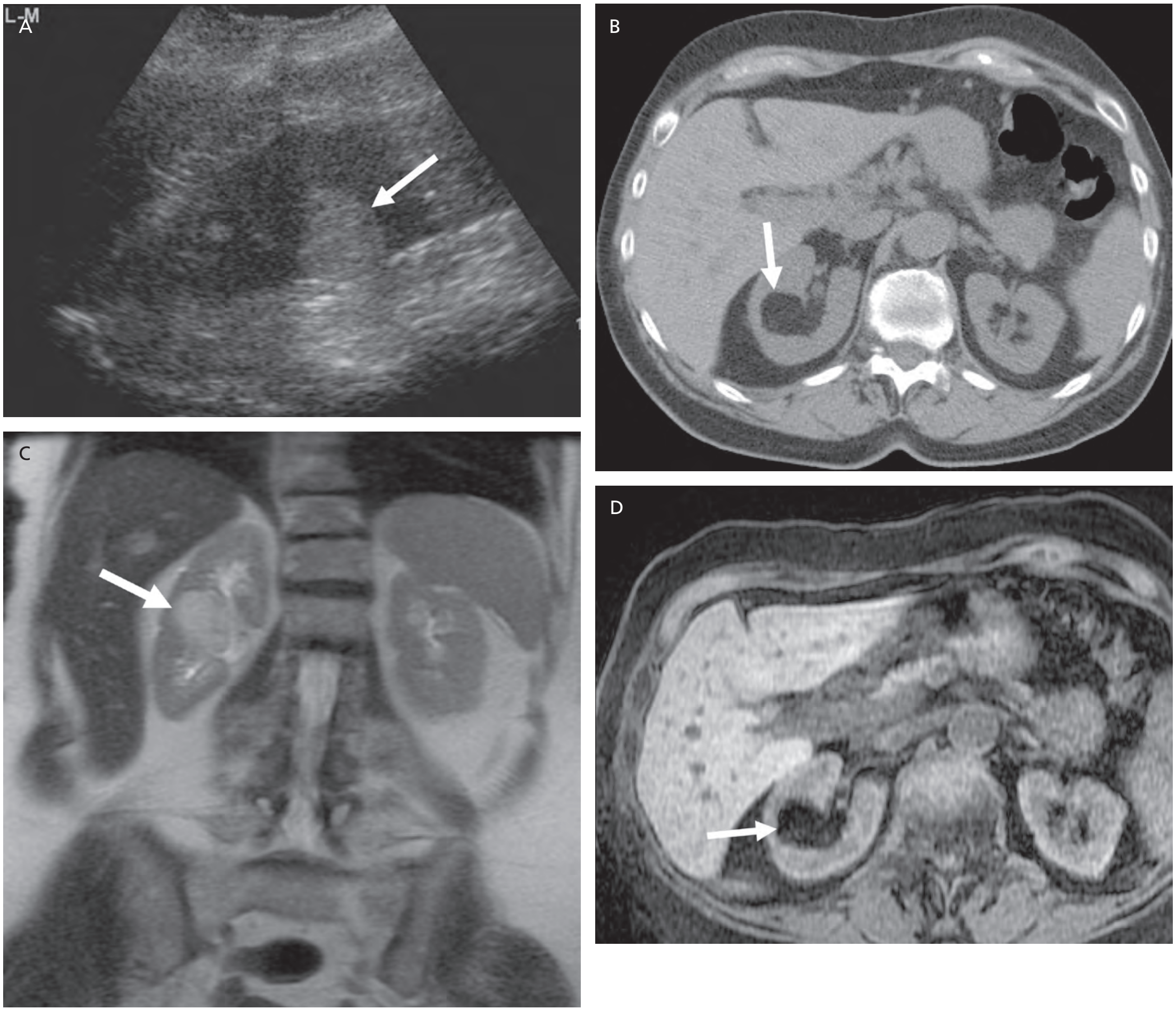

Figure 109.7 Renal angiomyolipoma: imaging features. (A) Longitudinal sonogram demonstrates a well-marginated uniformly hyperechoic renal mass (arrow). (B) Axial unenhanced CT scan shows a well-circumscribed, fat-containing right renal mass (arrow), with a density of –85 HU. (C) This mass is hyperintense on this T1-weighted coronal MR image. (D) This lesion (arrow) shows signal drop out on this axial, fat-suppressed MR image.

confidence on unenhanced CT when there are one or more regions of fat in a noncalcified renal lesion. They are typically well marginated, cortical in location, and predominantly fatty lesions with heterogeneous regions of soft tissue attenuation interspersed throughout the mass. Although the soft tissue components of the mass may enhance with intravenous contrast, this is not a dominant feature of most AMLs [55–59].

Sonographically, small AMLs appear as uniformly hyperechoic lesions (see Figure 109.7). Unfortunately, this sonographic appearance is also seen in 32% of small (<3 cm) RCCs. Echogenic carcinomas are more likely to have a hypoechoic rim and cystic areas, while AMLs are more likely to demonstrate acoustic shadowing and no hypoechoic rim. These findings are not sufficiently sensitive or specific to confidently make the diagnosis, so CT or MR is required for further evaluation. Larger AMLs are more complex on ultrasound and difficult to diagnose. On MRI (see Figure 109.7), most AMLs can be readily characterized with fat-suppression techniques, including combined T1-weighted regular (in-phase) and fat-suppressed images or combined T1-weighted in-phase and out-of-phase spoiled gradient-echo sequences [55–59].

The absence of a complete elastin layer in the blood vessels of AMLs predisposes these lesions to aneurysm formation and hemorrhage. The aneurysms, commonly seen on angiography, may not be appreciated on cross-

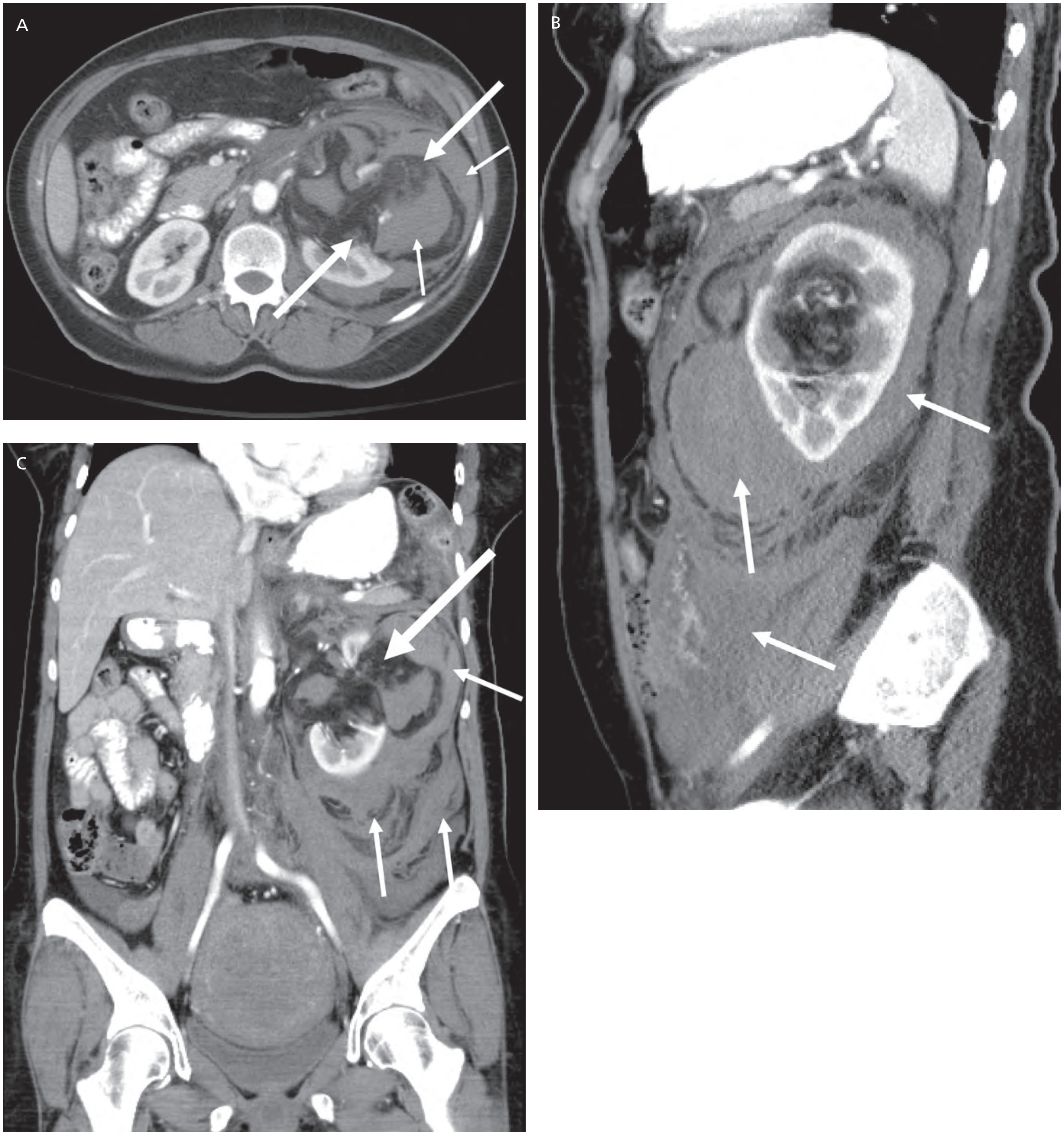

Figure 109.8 Hemorrhagic angiomyolipoma: CT features. (A) Axial, (B) sagittal, and (C) coronal CT images show a large fat-containing angiomyolipoma (large arrows) associated with a large renal and perirenal hematoma (small arrows).

sectional imaging studies. Hemorrhage is not uncommon. When the lesions bleed, they can present a diagnostic dilemma as the fat may be masked by the hemorrhage. Lesions larger than 3.5–4.0 cm in diameter are believed to have an increased risk of hemorrhage, and are often electively resected with nephron-sparing surgery. In patients with high surgical risk and those with tuberous sclerosis who may have limited renal reserve, selective arterial embolization can be performed [55–59].

There have been reported cases of macroscopic fat in clear-cell RCCs. In these cases, extensive calcification is also present in the mass. Since calcifications in AMLs and fat without calcifications in RCCs are both extremely rare, a fatty noncalcified renal mass is considered diagnostic of AML. Other fat-containing renal lesions that

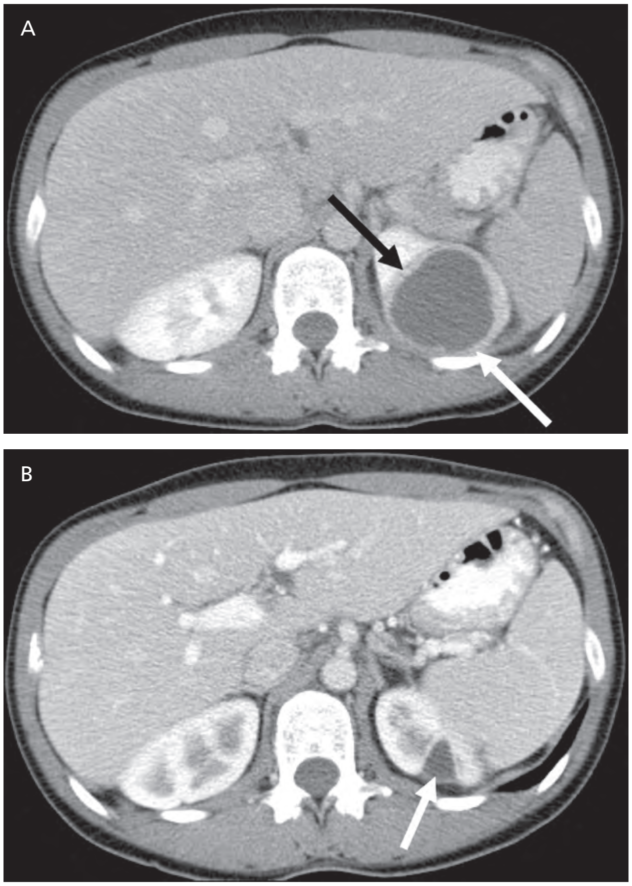

Figure 109.9 Renal abscess causing a low-density renal mass. (A) Transverse contrast-enhanced CT scan shows a thick-walled low-density mass (arrows) at the upper pole of the left kidney. (B) Scan obtained 3 months after the completion of antibiotic therapy shows a much smaller residual renal mass (arrow).

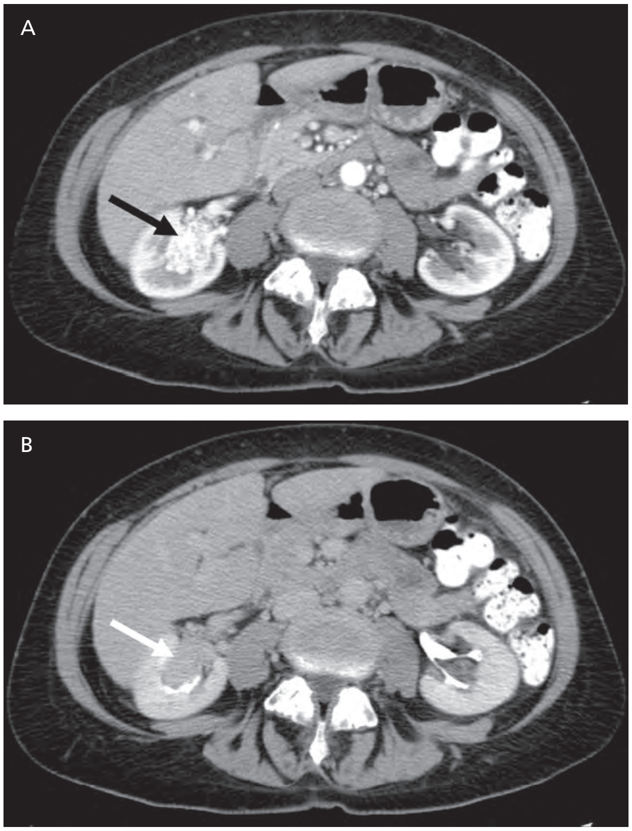

Figure 109.11 Arteriovenous malformation simulating a renal pelvic mass. (A) Axial CT scan obtained during the corticomedullary phase of enhancement shows multiple tubular enhancing structures (arrow) in the right renal pelvis. (B) On the excretory phase images, they simulate a right renal pelvic tumor (arrow). Parapelvic cysts are present in the left kidney.

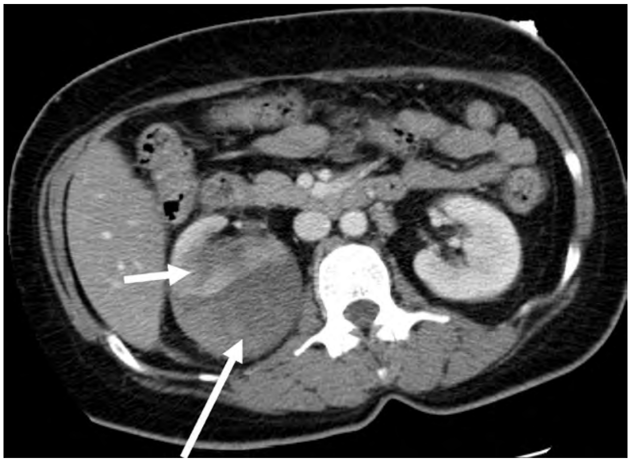

Figure 109.10 Perinephric hematoma causing a Page kidney. Axial contrast-enhanced CT scan shows a large perinephric hematoma (long arrow) causing compression of the right kidney. Note the diminished nephrogram of the compressed right kidney (short arrow).

are extremely rare and are not usually included in the differential diagnosis are lipoma, liposarcoma and, even more rarely, oncocytomas [55–59].

Lipid-poor AMLs (approximately 5%) pose a diagnostic problem in that they appear as solid enhancing masses that have been considered indistinguishable from RCCs based on imaging findings. However, recent studies have suggested that a small (<3 cm) hyperattenuating lesion on noncontrast CT which demonstrates homogeneous enhancement has a strong likelihood of being a benign lesion [55–59]. This lesion can be further evaluated with MRI to assess for microscopic fat. Percutaneous biopsy can also be performed on these lesions.

Oncocytoma

Oncocytomas are benign renal cell neoplasms that account for approximately 5% of adult renal epithelial

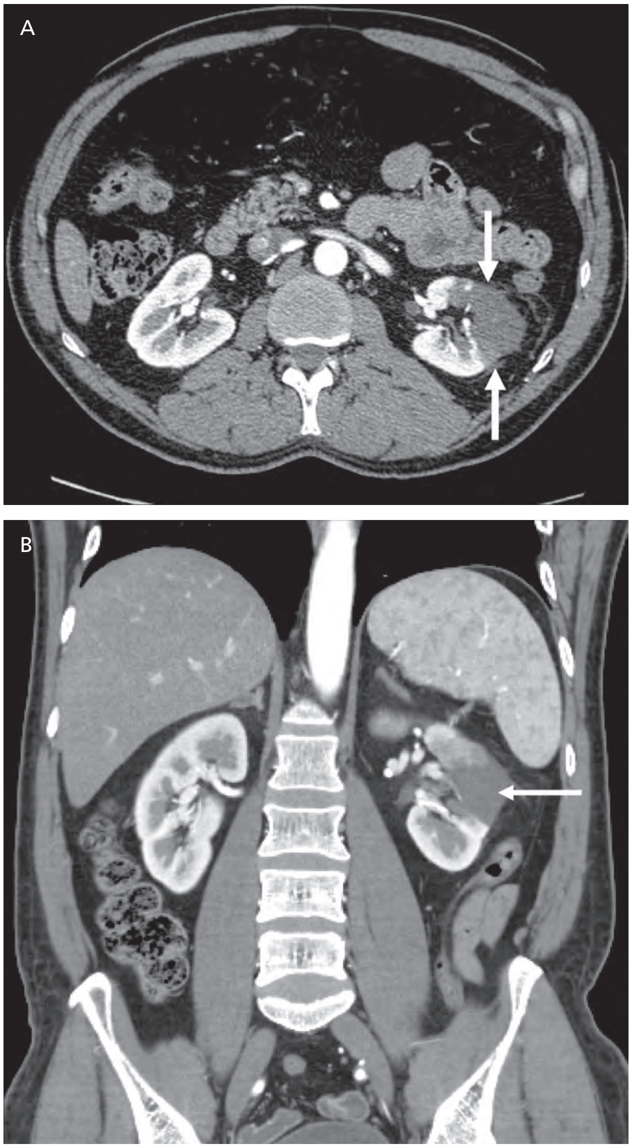

Figure 109.12 Renal infarct simulating a hypovascular renal mass. (A) Axial and (B) coronal reformatted contrast-enhanced CT images show a wedge-shaped region of markedly decreased enhancement (arrows) along the lateral aspect of the interpolar region of the left kidney.

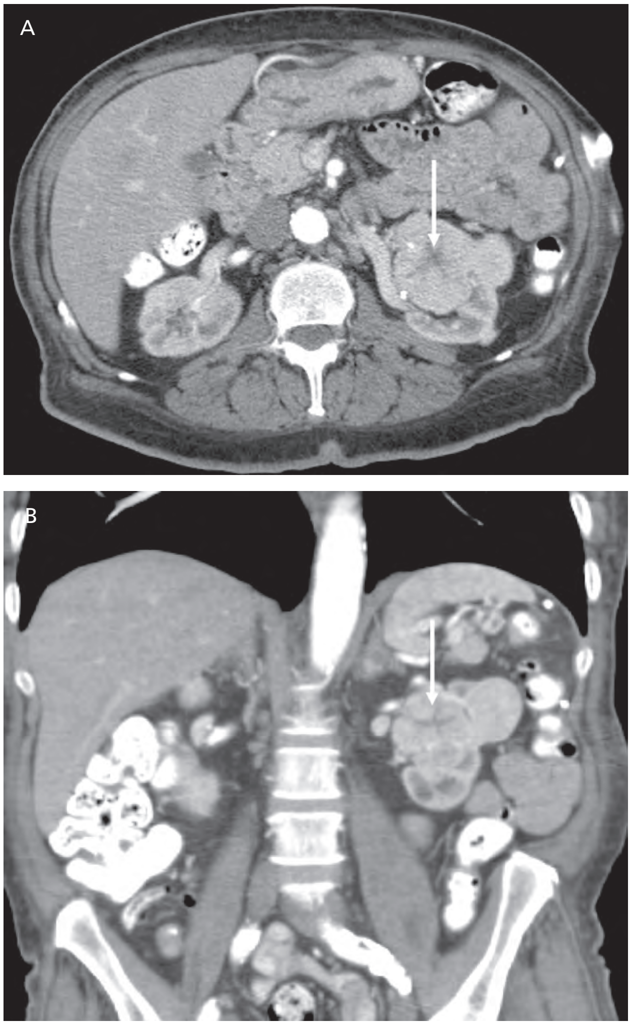

Figure 109.13 Renal oncocytomas: CT features. Multiple renal masses are identified on (A) axial and (B) coronal contrast-enhanced CT scans. Note the spoke-wheel pattern (arrow) of enhancement.

neoplasms in surgical series. They are more common in men than in women, and their peak incidence is in the seventh decade. There are some imaging features that suggest the diagnosis of oncocytoma, including homogenous enhancement and a central stellate fibrotic nonenhancing scar in approximately one-third of cases. The scar can appear high signal on T2- weighted sequences. Classic CT (Figure 109.13), MRI, and angiographic findings for oncocytoma including a spoke-wheel pattern, a homogeneous tumor blush, and a sharp, smooth rim. Oncocytomas typically do not have perinephric stranding. Unfortunately, the imaging features of oncocytomas demonstrate considerable overlap with those of RCCs, particularly the clear-cell subtype, and therefore cannot be reliably used for diagnosis. Indeed, oncocytomas often manifest as a complex hypervascular mass that is sometimes associated with adjacent neovascularity and perinephric stranding, findings that are worrisome for a clear-cell carcinoma. Advances in immunocytochemical analysis and cytogenetics may be helpful in distinguishing oncocytoma from RCC in the future, but at this time oncocytomas cannot be reliably diagnosed with percutaneous biopsy, and they typically are surgically resected [60–62].

Other benign solid renal masses

There are other benign solid renal lesions that cannot be reliably distinguished from RCCs, though some have imaging features that may suggest the diagnosis.

Papillary adenomas and renomedullary interstitial cell tumors are less than 5 mm in diameter and are common at autopsy [4]. Metanephric adenomas are usually solid and hyperattenuating on noncontrast CT and 20% contain calcification. Hemangiomas and lymphangiomas typically arise in the renal pyramids or pelvis. Leiomyomas commonly appear as well-circumscribed homogeneous exophytic solid masses that demonstrate uniform enhancement with intravenous contrast. Juxtaglomerular cell neoplasm (reninoma) is an endocrine tumor, which typically occurs in the second or third decades of life, and is twice as common in females as in males. Patients present with hypertension and hypokalemia. These lesions typically appear as well-circumscribed cortical tumors of less than 3 cm in diameter. Despite the fact that they are such vascular lesions pathologically, they appear hypovascular on contrast CT, possibly due to renin-induced vasoconstriction [4]. Mixed epithelial and stromal tumors consist of solid and cystic areas that may herniate into the renal pelvis. The observation of some of these features may be sufficient to raise the possibility of a benign lesion and in some cases biopsy should be considered rather than immediate surgery [4].

Renal cell carcinoma

RCC is the eighth most common malignancy and accounts for 2–3% of new cancers in the USA. RCC typically presents in the fifth to seventh decade of life, and is two to three times more common in men than in women, and slightly more common in blacks than in whites. The tumors are usually solitary, but can be multifocal in 6–25%. In patients with certain genetic conditions, such as von Hippel-Lindau disease (Figure 109.14), hereditary papillary renal cancer (Figure 109.15), and possibly tuberous sclerosis, multifocality is common. Indeed, multifocal tumors are seen in 87% of patients with von Hippel–Lindau disease [63–65]. RCC is also more common in patients with acquired cystic renal disease, with a three to six times increased risk in patients on long-term dialysis [63, 64]. Because RCCs may be multifocal or bilateral, both kidneys must be scrutinized when staging the lesion prior to surgical or percutaneous intervention.

In recent years, the incidence of RCC has increased due to several factors. In large part this is secondary to the increased incidental detection on imaging studies. Now nearly two-thirds of renal neoplasms are found incidentally compared to approximately 10% in the early 1970s. There has also been an increased rate of survival in patients with RCC primarily due to the fact that these lesions are found when small in asymptomatic individuals. There is some evidence suggesting that asymptomatic tumors are smaller and of lower grade and earlier stage than symptomatic lesions. The overall 5-year survival rate is approximately 85% for incidentally detected tumors compared to 53% in symptomatic individuals [63, 64]. Therefore, radiologists have

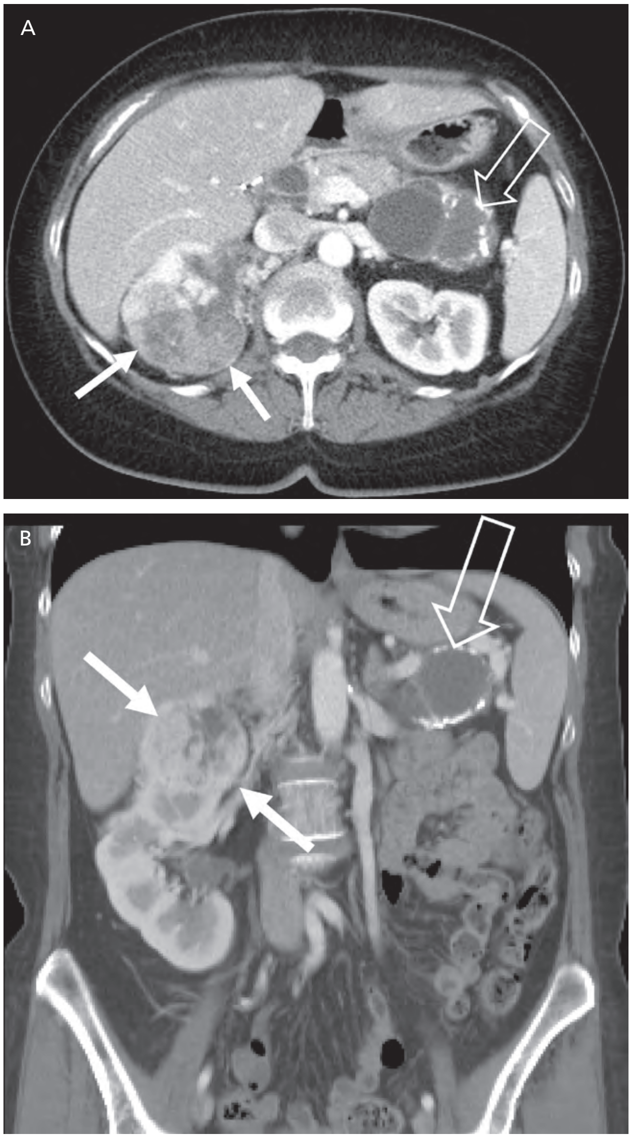

Figure 109.14 Synchronous renal cell carcinoma and mucinous adenocarcinoma of the pancreas in a patient with von Hippel–Lindau syndrome. (A) Axial and (B) coronal reformatted CT images show a clear-cell renal cell carcinoma in the upper pole of the right kidney (solid arrows) and calcified and noncalcified cystic lesions (open arrow) in the pancreatic body and tail. The calcified cystic lesion was a mucinous cystadenocarcinoma.

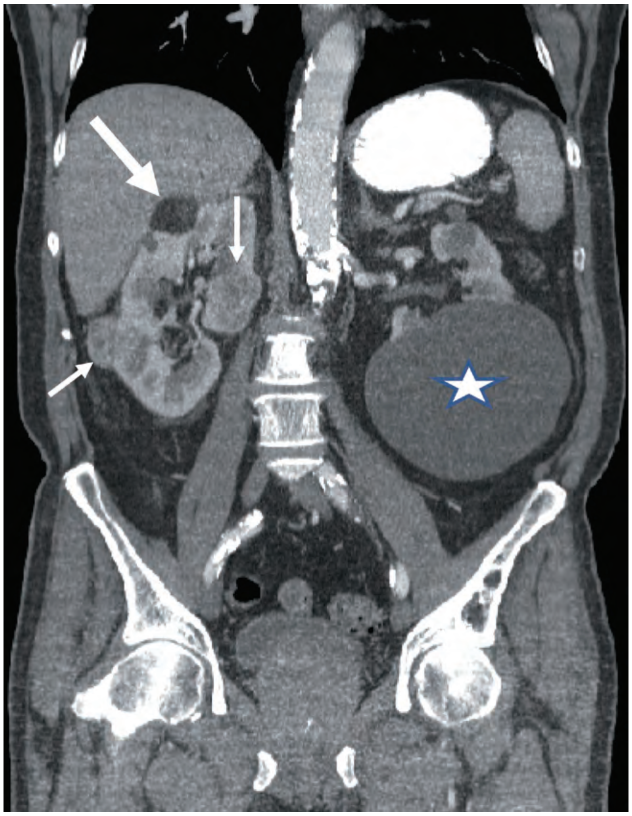

Figure 109.15 Hereditary papillary renal cancer. Coronal reformatted contrast-enhanced CT image shows synchronous hypervascular neoplasms in the right kidney (small arrows). Note the angiomyolipoma (large arrow) and the large left benign renal cyst (star).

played and continue to play a significant role in finding early cancers and improving patient survival.

According to the 1997 Heidelberg classification, the most common RCC histologic subtypes are: clear-cell adenocarcinoma (65–75%), papillary adenocarcinoma (15%), chromophobe (5%), collecting duct (1%), and unclassified carcinomas (4%). Clear-cell RCC, also known as conventional RCC, has a much greater malignant potential than papillary and chromophobe RCCs. Since the prognosis varies among the subtypes of RCC (Table 109.2), being able to distinguish these with imaging can have important clinical implications in the management of certain groups of patients [66–72].

Clear-cell RCC is the most vascular type of all malignant renal cortical tumors, as shown by its greater degree of enhancement after administration of intravenous contrast. It most commonly presents with a mixed enhancement pattern of both hypervascular soft tissue components and low attenuation areas that correspond to necrotic or cystic changes. Kim *et al*. showed that an increase in attenuation of 84 HU in the corticomedullary phase differentiates clear-cell from nonclear-cell tumors with a sensitivity of 74% and a specificity of 100% [73].

Table 109.2 Histologic subtypes of renal cell carcinoma.

Clear-cell renal cell carcinoma
Multilocular clear-cell carcinoma
Papillary renal cell carcinoma
Chromophobe renal cell carcinoma
Collecting duct carcinoma
Translocation carcinomas
Renal cell carcinoma associated with neuroblastoma
Mucinous tubular and spindle cell carcinoma
Renal cell carcinoma unclassified

Papillary RCC, on the other hand, demonstrates a low degree of enhancement relative to renal cortical enhancement in either a homogenous pattern or with low-level peripheral enhancement. A low tumor-to-aorta enhancement ratio or tumor-to-normal renal parenchyma enhancement ratio is highly indicative of papillary RCC [74, 75].

Chromophobe RCCs are more variable in their degree and pattern of enhancement. Renal medullary carcinoma is a recently described malignant renal neoplasm occurring in patients with sickle cell anemia. It is centered in the medulla and microscopically exhibits a reticular, yolk sac or adenoid cystic appearance. This neoplasm exhibits aggressive behavior [66–72].

Generally, the presence of calcifications in a solid renal mass (Figure 109.16) suggests malignancy. Rarely, a malignant renal tumor may be diffusely calcified [76]. RCCs typically show de-enhancement of contrast of greater than 15 HU when comparing the corticomedullary phase to the excretory phase (Figure 109.17).

Staging renal cell carcinomas

RCCs spread via a number of pathways. They may invade locally, initially through the renal capsule into the adjacent perinephric fat. Upper pole tumors may invade the ipsilateral adrenal gland. More advanced tumors can involve the adjacent musculature or extend beyond Gerota's fascia to involve the liver, spleen, pancreas, duodenum, and colon. RCCs may invade the renal vein and propagate into the inferior vena cava and right atrium. Hematogenous metastases most commonly go to the lungs and bone. RCCs can also spread by lymphatic routes, beginning with the renal hilar lymph nodes and then the regional para-aortic lymph nodes [77–83].

Accurate preoperative staging of patients with RCC is of paramount importance in selecting the most suitable therapy, guiding surgical intervention, and assessing patient prognosis. The 40-year-old Robson

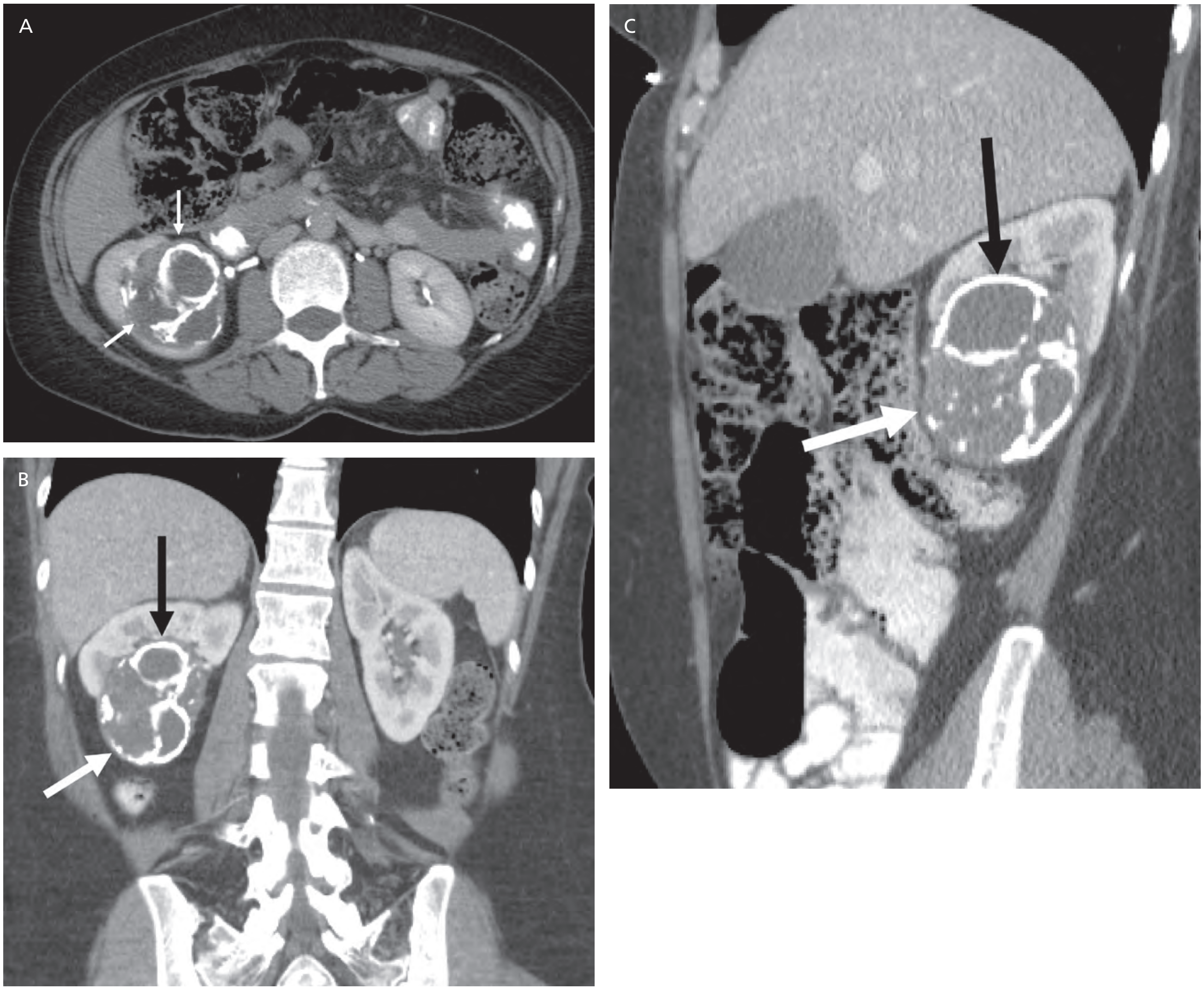

Figure 109.16 Calcified renal cell carcinoma. Calcified renal cell carcinoma (arrows) is seen at the lower pole of the right kidney on (A) axial, (B) coronal reformatted, and (C) sagittal reformatted contrast-enhanced CT images.

classification of RCC was replaced with the TNM staging system, developed in 2002 by the American Joint Committee on Cancer and the International Union Against Cancer (Tables 109.3 and 109.4), because the latter adapts more easily to changing patterns of diagnosis and therapy for RCC. Indeed, it appears that TNM staging is evolving with the advance of surgical techniques, and is now being challenged by the advent of new, minimally invasive treatment methods such as cryoablation and radiofrequency ablation. MDCT and MRI are superb for T staging of local tumor extent and M staging of distant metastasis. However, both imaging tests perform less well with N staging. Since FDG-PET appears to be unreliable in the detection of RCC and its metastases, research efforts should be directed at finding malignant adenopathy of RCC [77–83].

T staging

TNM classes T1 and T2 include all primary RCCs that are confined to the renal capsule (Figures 109.18 and 109.19). The TNM classification of 2002 distinguishes between T1a, which defines a RCC with a maximum diameter of 4 cm or less, and T1b, which defines a RCC whose maximum diameter is larger than 4 cm but smaller than 7 cm. Aside from potential differences in prognosis, the most likely reason for the migration of definitions for TNM classes T1 (now T1a and T1b) and T2 lies in the development of new surgical techniques of renal tumor resection [77–83].

It may be difficult to detect subtle invasion of RCC beyond the renal capsule on cross-sectional imaging (Figure 109.20). Anatomically, the true renal capsule rep-

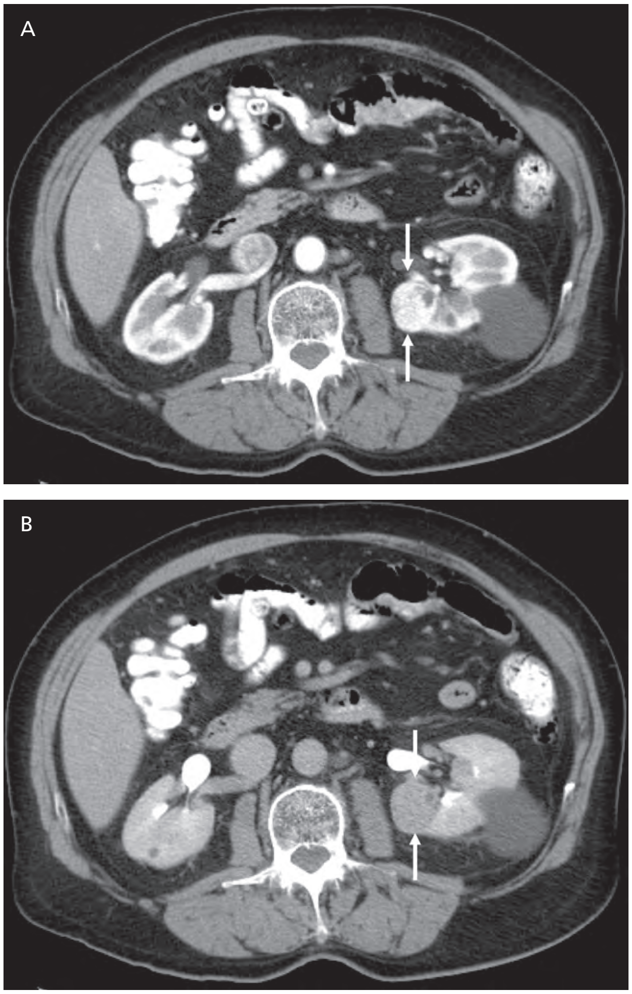

Figure 109.17 De-enhancement of renal cell carcinoma: CT findings. (A) Scan obtained during the cortical medullary phase shows an enhancing mass along the medial aspect of the left kidney (arrows). A simple renal cyst is also present. (B) 3-min delayed image shows that the contrast material has rapidly washed out of the tumor (arrow) and it is now hypodense relative to normal kidney. Bilateral simple renal cysts are present.

resents the fibrotic outer surface layer surrounding the renal parenchyma. This layer, however, is ill-defined or missing in the renal hilum. Pathologically, RCC induces reactions within the kidney and within the perirenal fat that may make it difficult to distinguish between the true renal capsule and the pseudocapsular structures [78, 79].

In terms of T3b and T3c lesions, both MRI and MDCT are comparable in assessing tumor invasion of the renal vein and extension into the inferior vena cava either below or above the diaphragm. Extension of RCC tumor thrombus above the diaphragm defines TNM class T3c (Figure 109.21) [78, 79].

T4 lesions are characterized by tumor extension through Gerota's fascia. This assessment may be difficult

Table 109.3 TNM staging system of renal cell carcinoma. (reproduced from Edge SB, Byrd DR, Compton CC, eds. AJCC Cancer Staging Manual. 7th ed. New York, NY: Springer, 2010).

Primary tumor (T)	
TX	Primary tumor cannot be assessed
T0	No evidence of primary tumor
Ta	Papillary noninvasive carcinoma
Tis	Carcinoma *in situ*
T1	Confined to kidney T1a <4 cm T1b <7 cm
T2	Confined to kidney: > 7 cm
T3	Confined to Gerota's fascia T3A: extending to ipsilateral adrenal gland or perirenal fat T3b: extending to renal vein or inferior vena cava (IVC) below diaphragm T3c: extending to IVC above diaphragm
T4	Tumor extends beyond Gerota's fascia
*Regional lymph nodes (N)**	
NX	Regional lymph nodes cannot be assessed
N0	No regional lymph node metastasis
N1	Metastasis in a single lymph node, 2 cm or less in greatest dimension
N2	Metastasis in a single lymph node, >2 cm but not >5 cm in greatest dimension; or multiple lymph nodes, none >5 cm in greatest dimension
N3	Metastasis in a lymph node, >5 cm in greatest dimension
Distant metastasis (M)	
M0	No distant metastasis
M1	Distant metastasis

*Laterality does not affect the N classification.

Table 109.4 TNM staging system of renal cell carcinoma (reproduced from Edge SB, Byrd DR, Compton CC, eds. AJCC Cancer Staging Manual. 7th ed. New York, NY: Springer, 2010).

Stage 0a	Ta	N0	M0
Stage 0is	Tis	N0	M0
Stage I	T1	N0	M0
Stage II	T2	N0	M0
Stage III	T3	N0	M0
Stage IV	T4	N0	M0
	Any T	N1	M0
	Any T	N2	M0
	Any T	N3	M0
	Any T	Any N	M1

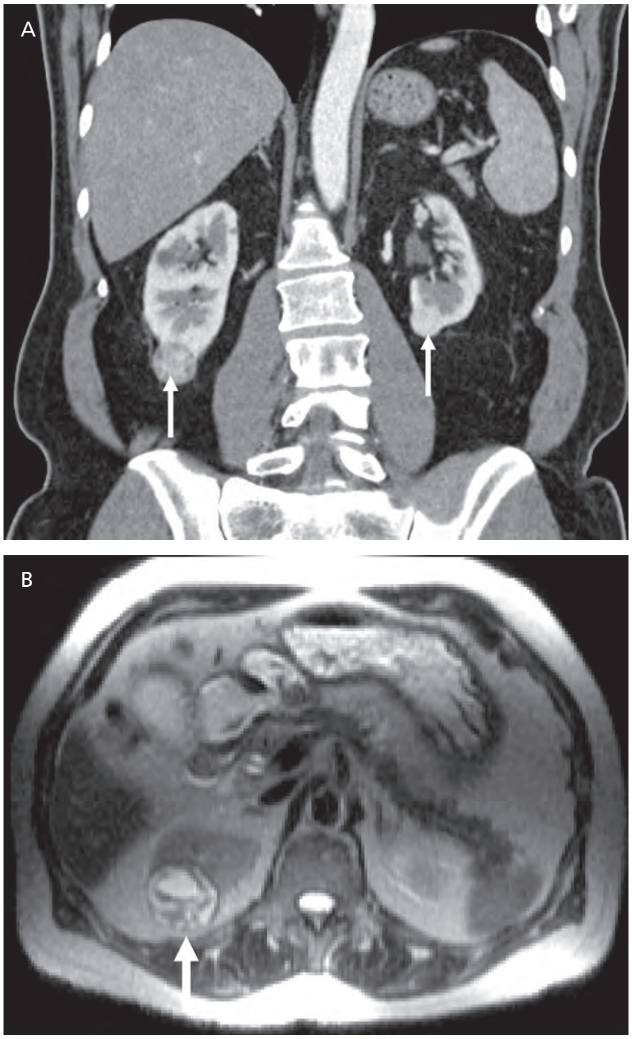

Figure 109.18 T1a renal cell carcinoma. (A) Coronal reformatted CT image shows bilateral small lower pole renal tumors (arrows), which are limited by the renal fascia. (B) Axial T2-weighted MR image shows a complex renal neoplasm (arrow) confined by the renal fascia.

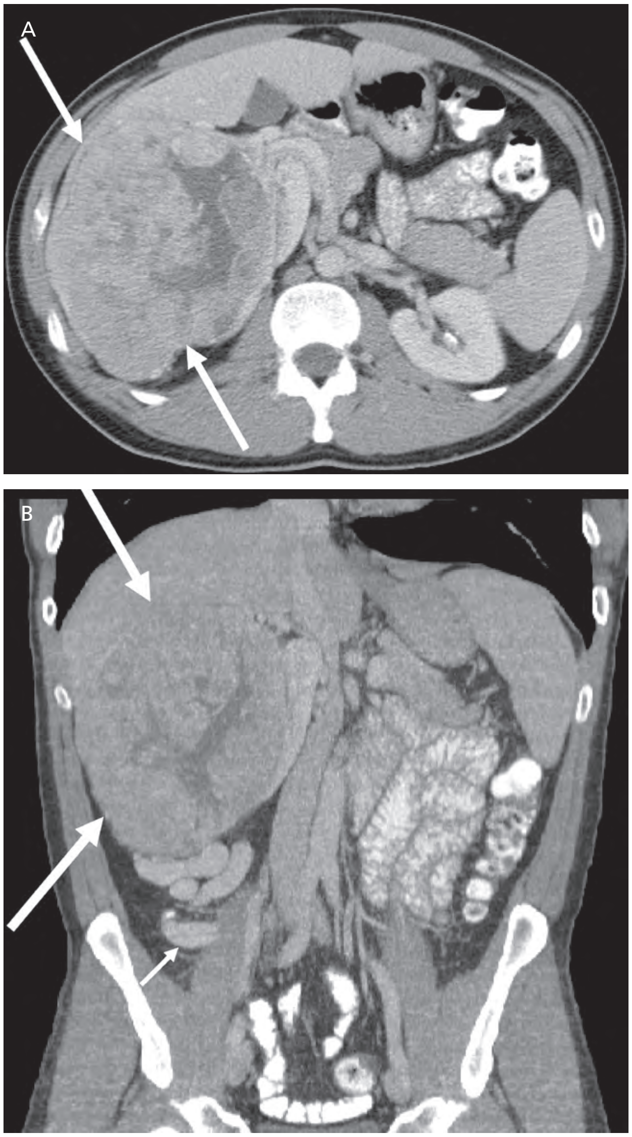

Figure 109.19 T2 renal cell carcinoma. (A) Axial CT image shows a 10.5-cm complex mass (arrows) replacing the majority of the right kidney. Despite its large size, the tumor was limited to the kidney at surgery. (B) Coronal reformatted CT image shows parasitization of retroperitoneal vessels (small arrow) feeding this large neoplasm (large arrows).

on cross-sectional imaging when the fascia is only minimally transgressed.

N staging

Involvement of regional lymph nodes has several different classifications in the TNM system (Tables 109.2 and 109.3). The most important lymph nodes to evaluate when staging patients with RCC include: nodes along the renal arteries and paracaval lymph nodes for right-sided tumors; para-aortic lymph nodes for left-sided tumors (see Figure 109.20B); and nodes located at the levels of the renal hilum or renal artery. Metastasis in regional lymph nodes without synchronous distant metastasis is found in 10–15% of patients with RCC [83, 84].

As with most neoplasms, the detection of lymph node metastases remains problematic in patients with RCC. Current MDCT and MRI criteria for suggesting adenopathy are lymph nodes that have a short-axis diameter of 1 cm or more and the presence of a prominent node that is more spherical rather than kidney shaped and has lost its hilar fat. Additionally, asymmetric grouping of three or more smaller lymph nodes may also be a sign of lymphatic tumor spread to the renal hilum. Further confounding the accuracy of cross-sectional imaging in detecting adenopathy is the fact

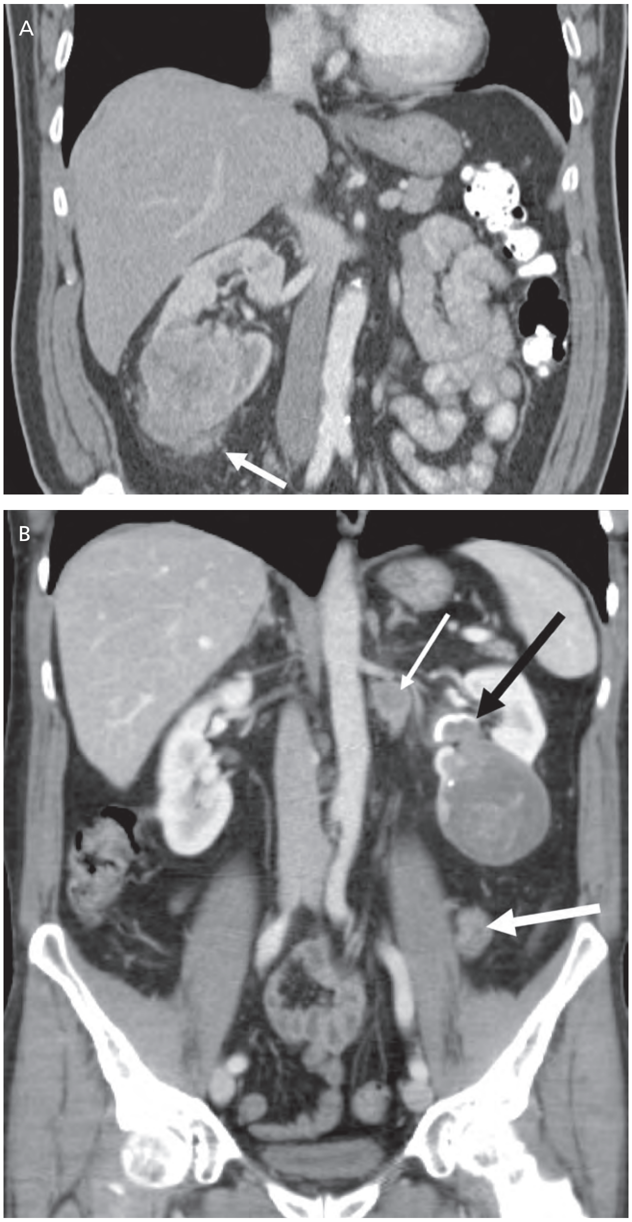

Figure 109.20 T3a, N2 renal cell carcinoma. (A) Coronal reformatted CT image depicts a 6.5-cm tumor extending through the right renal capsule (arrow) but confined by Gerota's fascia. (B) Coronal reformatted CT image in a different patient obtained during the excretory phase shows tumor invasion of the renal pelvis (black arrow). There is left renal hilar adenopathy (small white arrow) and a left paraspinous metastasis (large white arrow).

that more than 50% of enlarged regional lymph nodes exhibit only hyperplastic or inflammatory change pathologically [83, 84].

M staging

Distant metastases from RCC, M1 disease, includes all metastases that are either extranodal or involve nonregional lymph nodes. Metastases are most frequently found in the lung (31%) (Figure 109.22), bone (15%), brain (8%), and liver (5%). However, any other organ can be involved [29]. While metastatic RCC requires systemic therapy, surgical excision of the primary lesion appears to be an integral part of systemic therapy for metastatic RCC [85].

MDCT is the preferred means of M staging patients with RCC because it is superior to MRI in detecting pulmonary metastases. As stated above, FDG-PET at the present time appears too unreliable to recommend its routine use in the staging of RCC [86, 87].

Transitional cell carcinoma

Urothelial tumors of the renal calyces and pelvis account for approximately 7% of primary renal tumors and 5% of all urinary tract neoplasms. TCCs comprise 90% of pelvicalyceal tumors, with squamous cell carcinoma (which is radiologically indistinguishable from TCC) and adenocarcinomas accounting for 10% of these neoplasms. Patients with previous or current urothelial neoplasm of the bladder are at increased risk of developing TCC of the kidney. Indeed, upper tract urothelial tumors have similar risk factors, epidemiologic distribution, and pathologic features. Other risk factors include certain chemical exposures, nonsteroidal anti-inflammatory drug (NSAID) abuse, and tobacco use. Because of the multicentric nature of TCC, the urotheluium of the kidneys, ureters, and bladder must be assessed in its entirety prior to treatment to exclude synchronous lesions. During follow-up studies, metachronous tumors must be excluded as well [88–98].

The intravenous pyelogram (IVP) has traditionally been the initial screening examination for the detection of upper urinary tract neoplasms for patients with hematuria. The IVP, however, has been shown to miss 40% of upper tract cancers. This technique has been replaced by CTU using MDCT [88–98].

There are three general appearances of TCC on MDCT:

- *A small hypodense lesion in the renal collecting system* (Figure 109.23) demonstrating soft tissue attenuation (<40 HU). On noncontrast images, these tumors have a density of approximately 30 HU, which can be differentiated from urine (0–20 HU), blood clot (50–75 HU), and calculi (>100 HU). There is moderate enhancement with washout on delayed images following intravenous contrast administration, but the degree of enhancement is usually less than that seen in patients with RCC. Some 85% of these lesions are early-stage, superficial papillary neoplasms, that on the excretory phase of CTU appear as sessile filling defects within the high density contrast excreted into the renal collecting system. In more advanced cases, the tumor expands

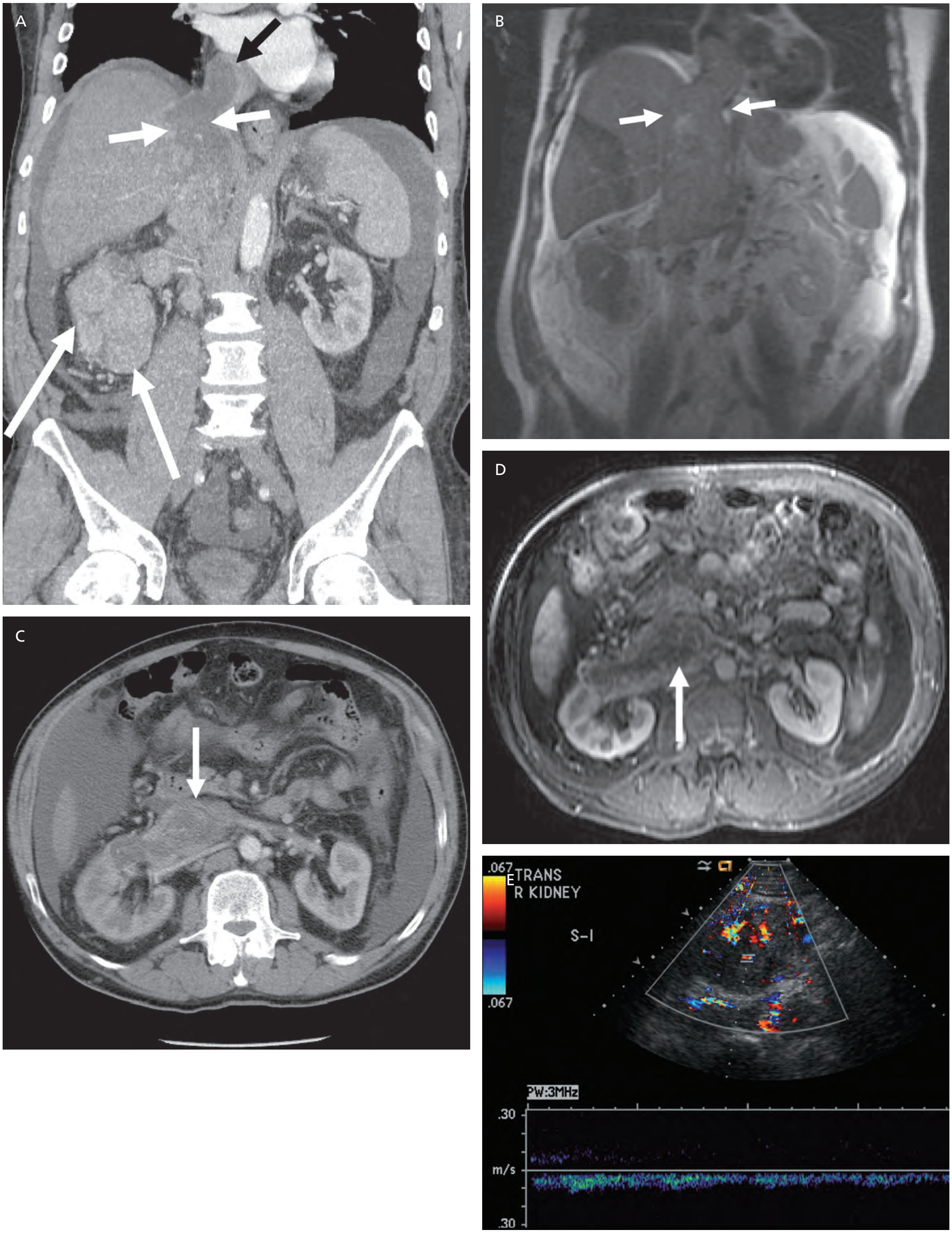

Figure 109.21 Stage T3c renal cell carcinoma. Coronal reformatted (A) CT and (B) MR images show a large right renal carcinoma (large white arrows) invading the left renal vein, inferior vena cava (small white arrows), and into the origin of the right atrium (black arrow). Axial (C) CT and (D) MR images better depict the invasion of the right renal vein (arrows) and inferior vena cava. (E) Color Doppler ultrasound shows flow within the tumor thrombus.

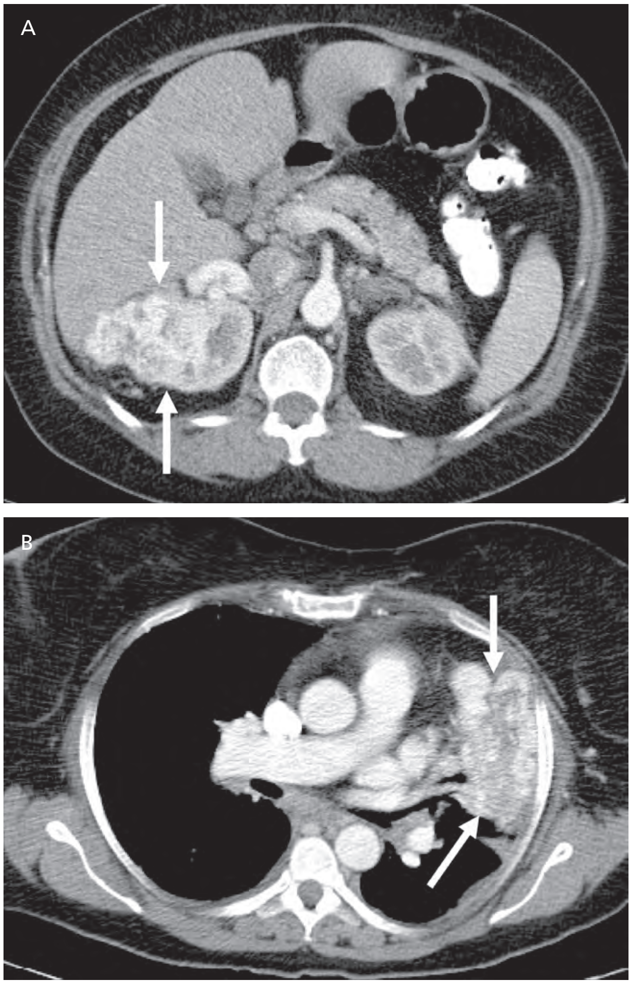

Figure 109.22 M1 renal cell carcinoma. (A) Axial, contrast-enhanced CT scan shows a hypervascular right renal mass (arrows). (B) Hypervascular metastasis (arrows) is present in the left chest and also invades the pleura.

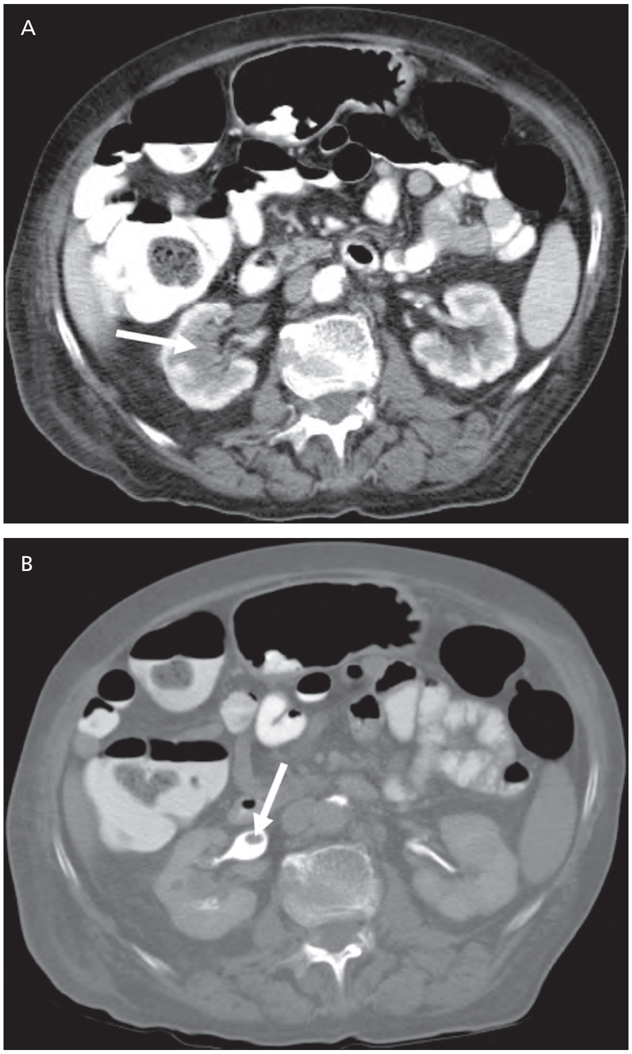

Figure 109.23 Transitional cell carcinoma. (A) CT scan obtained during the corticomedullary phase shows a hypodense mass (arrow) in the right renal pelvis and central pyramids. (B) CT scan obtained during the excretory phase shows a central mass and nodular tumor (arrow) within the right renal pelvis.

the collecting system with compression of the renal sinus fat.

- *Mural thickening, usually symmetric, of the renal collecting system, resulting in circumferential narrowing of the lumen*. This may lead to focal calyceal obstruction. The thickened wall may demonstrate enhancement, but a thick enhancing wall can also be seen with infection or with inflammation related to calculi, hemorrhage, recent stent placement or removal, or other surgical manipulation. In some cases biopsy may be necessary to distinguish benign from malignant etiologies.
- *An infiltrating hypoenhancing renal mass* (Figure 109.24) with poorly defined margins. Because TCCs arise from the urothelium, they are more centrally located than most RCCs. A TCC may contain stippled calcification and may be large and necrotic. It may distort the normal renal architecture. When it expands the kidney, the renal contour is usually preserved, in contradistinction to RCC. There may be obliteration of the renal sinus fat by tumor [88–98].

CTU is the primary noninvasive imaging test for the diagnosis and staging of upper urinary tract TCC. As stated before, MRU is an evolving technique for evaluating these lesions. Unfortunately, large studies comparing MRU with excretory urography or with CTU are lacking. MRU suffers from significant limitations of poorer spatial resolution than CTU, its inability to depict small amounts of calcification, and various artifacts, including motion artifacts from breathing and peristalsis. Moreover, the T2* effect of concentrated gadolinium excreted in the collecting system renders significant difficulties in evaluating the renal tract in

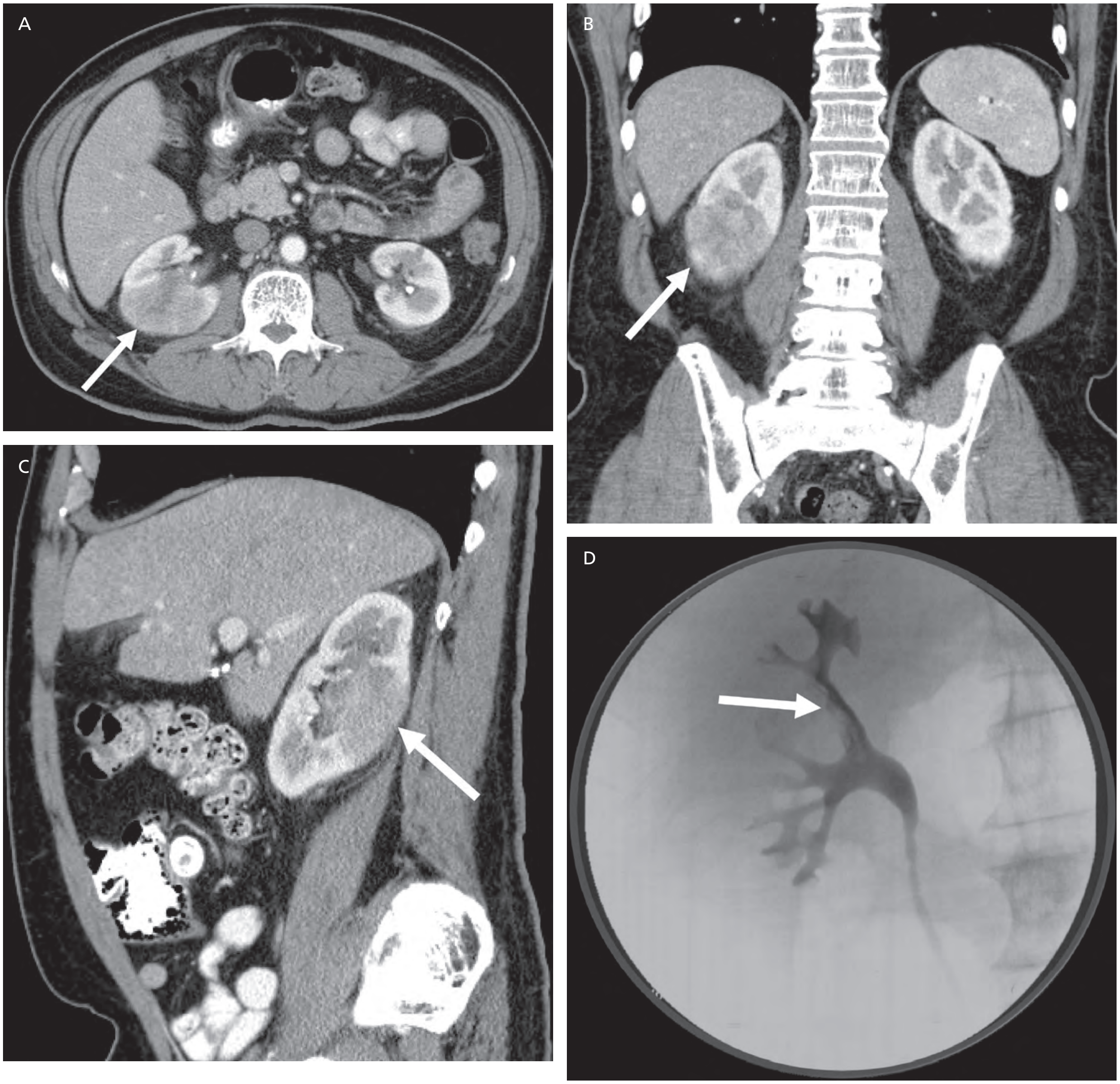

Figure 109.24 Transitional cell carcinoma of the right kidney: imaging findings. (A) Axial, (B) coronal, and (C) sagittal CT images show a large hypodense mass (arrows) extending from the renal pelvis into the renal cortex. (D) Retrograde pyelogram image shows the mass (arrow) deforming the renal pelvis.

the contrast-enhanced excretory phase T1-weighted sequences [24–27].

TCC is isointense to the renal parenchyma in both T1- and T2-weighted sequences so that MRU is best performed with gadolinium. The clinical role of MRU in patients with suspected TCC currently is limited, and should be considered as a first-line examination only when the patient has a contraindication to CTU, such as an allergy to iodine-based contrast agents [24–27].

Renal lymphoma

The kidney is one of the most common sites of extrarenal lymphoma. Nearly one-third of patients with non-Hodgkin lymphoma will have renal involvement at autopsy. Indeed, lymphoma is the third most common metastasis to the kidney following carcinoma of the lung and breast. The antemortem diagnosis is only made in 0.5–8.3%. The cells in lymphoma infiltrate

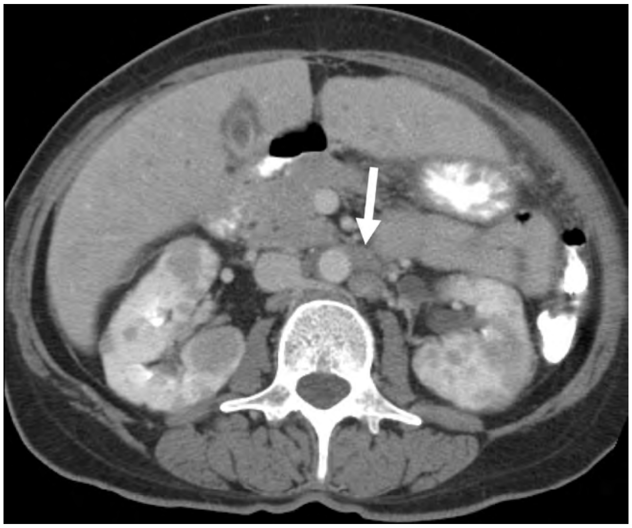

Figure 109.25 Renal lymphoma: CT findings. Multiple hypodense renal masses are present on this contrast-enhanced CT scan. Note the retroperitoneal adenopathy (arrow) as well.

between and do not destroy normal renal cells, and do not exhibit fibrosis, so the effect on renal function is typically minimal [99–102].

Since the kidneys normally do not contain lymphoid tissue, most cases of renal lymphoma are due to direct extension or hematogenous metastases. Retroperitoneal lymphoma can invade the renal capsule directly or infiltrate the renal sinus fat encasing the ureter, renal pelvis, and renal vessels. Lymphoma can then extend into the renal parenchyma via the medullary pyramids. When lymphoma involves the renal parenchyma by direct extension or hematogenous spread, it initially involves the renal interstitium, using vessels, collecting ducts, and nephrons as scaffolding [99–102].

There are five major patterns of presentation of renal lymphoma radiologically:

- Multiple renal masses that are often hyperdense compared to normal renal tissue on noncontrast CT scans due to the hypercellularity of the tumor. On contrast-enhanced scans, these lesion present as multiple, bilateral, hypodense (Figure 109.25) intraparenchymal masses, leading to a differential diagnosis of metastases, renal infarction, and renal infection.
- Diffuse renal infiltration causes nephromegaly but the renal arteries and veins remain patent despite encasement by tumor. On the early postcontrast images, the renal parenchyma remains relatively hypodense. On the nephrographic phase, relatively diminished enhancement is identified and there may be slight delay in excretion during the excretory phase. The differential diagnosis of this presentation of renal lymphoma includes RCC, TCC, and diffuse renal infection.

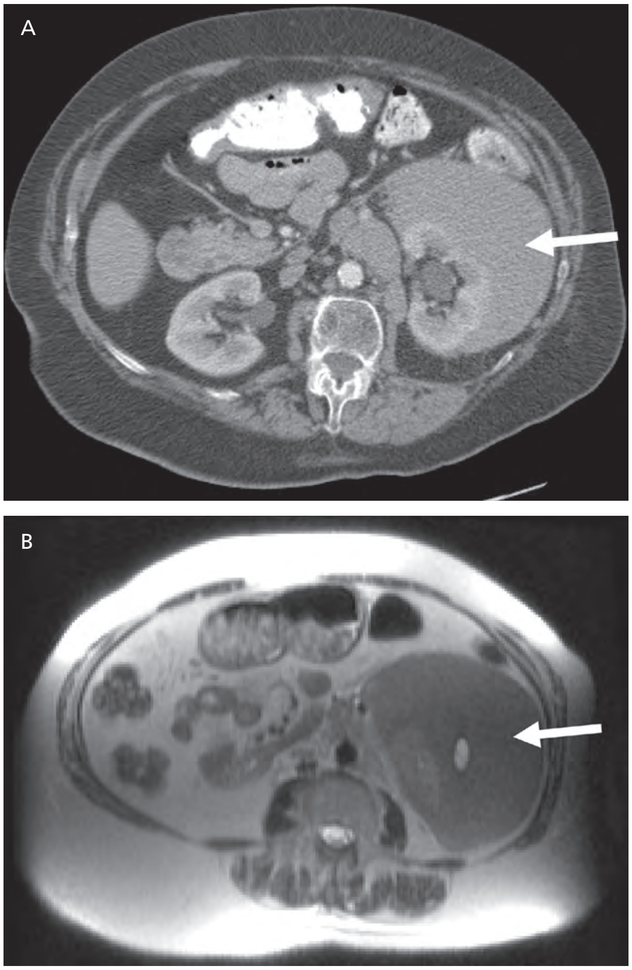

Figure 109.26 Perirenal lymphoma: imaging findings. Axial (A) CT and (B) MR images show a homogenous soft tissue mass (arrow) encasing the lateral aspect of the left kidney.

- The renal capsule or renal sinus may also be directly invaded by contiguous involvement from retroperitoneal lymphoma. Retroperionteal adenopathy is present and this may cause hydronephrosis.
- More rarely, renal lymphoma presents as a solitary, hypoattenuating, intra-parenchymal mass simulating a cortical tumor.
- Capsular (Figure 109.26) or perirenal involvement by lymphoma may occur with diffuse retroperitoneal adenopathy. The differential diagnosis of these cases includes perirenal hematoma and metastases [99–102].

Renal metastases

Renal metastases are quite common in patients with extrarenal neoplasms, and have been found in 7–13% of large autopsy series [17, 20]. The primary neoplasms that most commonly metastasize to the kidneys are lung (Figure 109.27), breast, and gastrointestinal cancers [85].

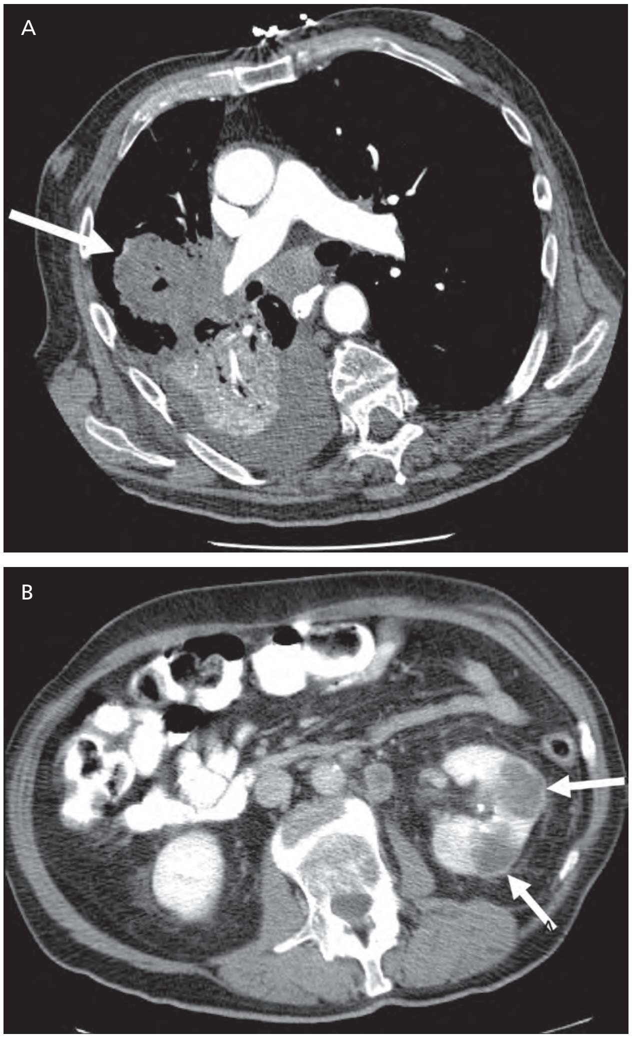

Figure 109.27 Metastatic lung cancer to the kidneys. (A) Contrast-enhanced CT scan of the chest shows a large cancer of the right upper lobe (arrow) invading the right hilum with mediastinal adenopathy. (B) Scan at the level of the kidneys show two hypodense metastases (arrows).

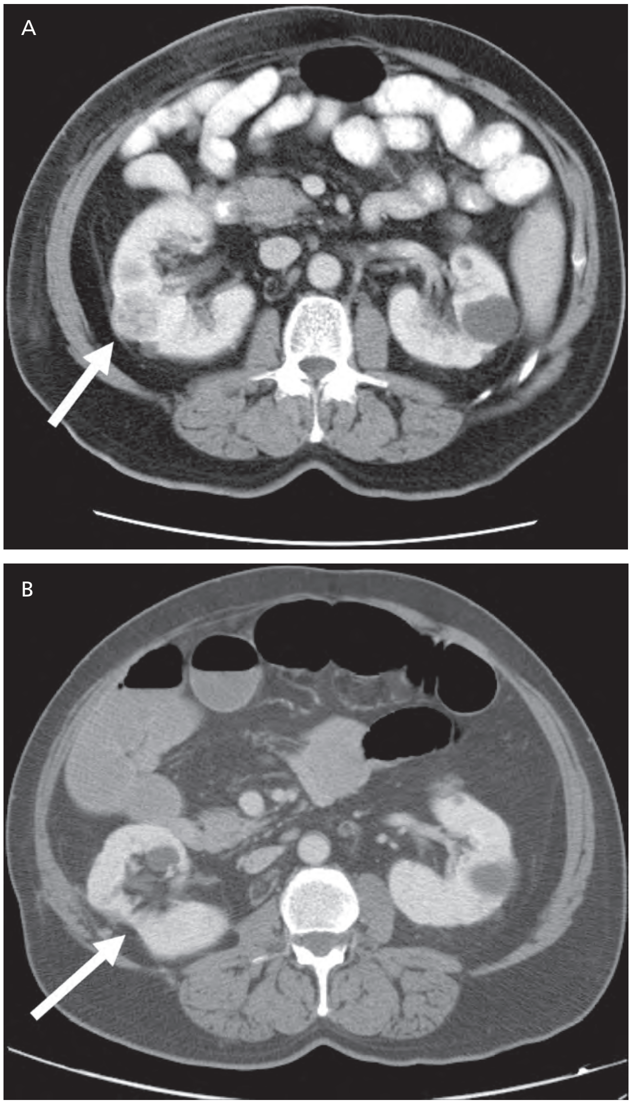

Figure 109.28 Nephron-sparing surgery: CT features. (A) Small hypervascular cortical right renal cell carcinoma (arrow) prior to surgery. (B) Deformity of the lateral aspect of the right kidney (arrow) is evident postoperatively.

These metastases usually have an indolent clinical behavior so were seldom discovered antemortem prior to the advent of cross-sectional imaging. By the time renal metastases are present, the patient usually has advanced disease. On rare occasions, a solitary renal metastasis may arise many years after the diagnosis of the primary neoplasm [1, 2].

Renal metastases, like lymphoma, can display an expansile or less commonly an infiltrative growth pattern. Most commonly, multiple bilateral masses are present. Solitary exophytic metastases are more common in patients with colon cancer, and perinephric tumor extension is identified in patients with melanoma [1, 2].

Patients who present with a solitary renal lesion and a known extrarenal primary tumor are a diagnostic challenge since the lesion may either be a metastasis or a synchronous renal neoplasm. The imaging findings in patients with renal metastases reflect the pathologic pattern of involvement and the nature of the primary tumor. A well-marginated hypovascular mass may be indistinguishable from a papillary RCC or lymphoma. Since infiltrative growth is atypically of renal cortical tumors, a solitary infiltrative renal mass in a patient with an extrarenal neoplasm most likely represents metastasis. Percutaneous biopsy will be needed for confirmation in these patients [26].

Imaging and nephron-sparing surgery

The increasing popularity of nephron-sparing surgery (Figure 109.28) has created a need to provide a more consistent, reproducible scoring system that quantifies renal tumor size, location and depth, the relationship of the tumor to the pelvicalyceal system, and detailed anatomic information concerning the renal arteries and veins to assist surgical decision-making and provide effective comparisons of treatment protocols and prognosis. Kuitov and Uzzo have developed a standardized nephrotomy scoring system based on quantification of the anatomic characteristics of renal masses displayed on MDCT and MRI, to replace the rather random and descriptive way of reporting renal masses [103]. This system is called the RENAL Nephrotomy Score and consists of (R)adius (tumor size as maximal diameter), (E) xophytic/endophytic properties of the tumor, (N) earness of tumor deepest portion to the collecting system or sinus, (A)nterior (a)/posterior (p) descriptor, and (L) ocation relative to the polar line. The suffix h (hilar) is assigned to tumors that abut the main renal artery or vein. Validation of this system is currently underway at a number of institutions [103].

Radiofrequency ablation (Figure 109.29) and cryoablation are now commonly used alternatives in the management of renal tumors. Tumors less than 4 cm in size are the best candidates for ablation. Renal tumors can be classified into three areas from an interventional standpoint: exophytic, parenchymal, or central. Exophytic lesions are the safest to treat. Central tumors are more challenging because of the proximity of the renal vessels, collecting system, and ureter. Tumor proximity to the vessels may lead to direct vascular injury or inadequate tumor margin treatment due to the heat sink effect. The ureter can also be injured, resulting in laceration or stricture [10–14]. Intraoperative ultrasound can show small tumors not detected at the time of surgery by conventional means.

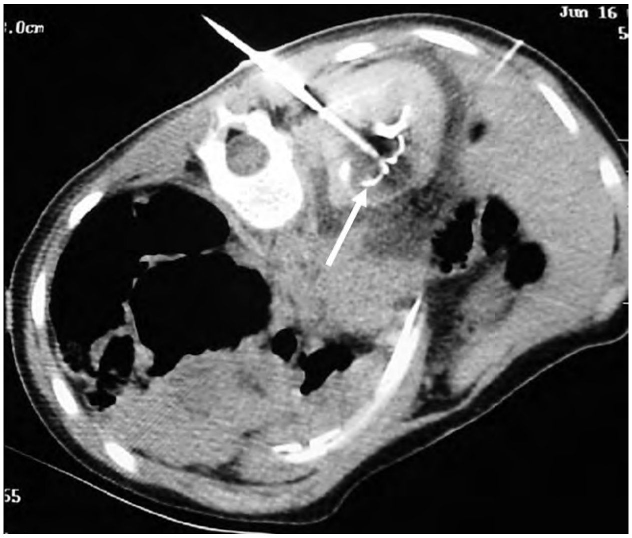

Figure 109.29 Radiofrequency ablation probe (arrow) deployed in a renal neoplasm. Note the patient is in the prone oblique position.

Recurrent cancer

Some 20–30% of patients with RCC that appears localized at the time of surgery relapse following radical nephrectomy. In the majority of cases, recurrence manifests as distant metastases rather than local disease, which occurs in less than 5% of cases. The stage of tumor at the time of presentation is the most important determinant of recurrent tumors. Other factors that increase the likelihood of recurrence include the presence of lymph node infiltration, high Furhman grade on histology, and the presence of sarcomatoid (spindle cell) architecture [104, 105].

The median time from nephrectomy to relapse is 15–18 months and 85% occur within 3 years. Tumors that involve lymph nodes tend to recur early, whereas very late relapse can be seen with isolated metastasis to the lung, bone, pancreas, or skeletal muscle. Lung metastases account for 50–60% of distant relapses. These metastases may produce parenchymal consolidation or manifest as a hemorrhagic or lymph node-related mass [103, 104].

Recurrent metastases in the pancreas typically appear hypervascular on CT (Figure 109.30) and MRI, unlike the typically hypovascular masses seen in primary pancreatic adenocarcinoma. These metastases often develop quite late following resection of the primary neoplasm [104, 105].

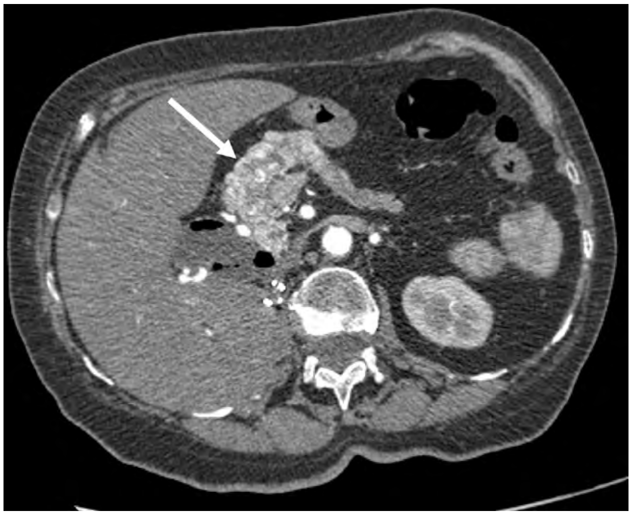

Figure 109.30 Hypervascular metastasis from renal cell carcinoma to the pancreatic head. Contrast-enhanced CT shows a large, nonobstructing mass in the pancreatic head which developed 7 years following resection of a right-sided renal cell carcinoma.

Local recurrence is unusual and produces an enhancing mass at the site of nephrectomy. These tumors may infiltrate the adjacent quadratus lumborum and psoas muscles. The colon and small bowel can be directly invaded and, when advanced, can produce mesenteric nodal disease or peritoneal carinomatosis [104, 105].

MDCT is the imaging test of choice for the detection of local recurrent disease and distant metastases. If the patient has a contrast allergy, gadolinium-enhanced MRI of the abdomen and pelvis can be performed along with a noncontrast CT scan of the chest. Although not recommended in the initial evaluation of patients with renal malignancies, FDG-PET may have a role in the detection of recurrent distal metastases, especially if conventional studies are equivocal and in differentiating recurrent tumor from postoperative fibrosis.

Conclusions

State-of-the-art MDCT, ultrasound, and MRI are leading to the earlier detection, better characterization, and improved staging of renal masses. As our increasing understanding of the diversity of renal neoplasia has been accompanied by innovative surgical and ablative techniques, cross-sectional imaging remains the linchpin in individualizing the treatment and follow-up of patients with renal masses.

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CHAPTER 110

Renal Mass Biopsy

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Introduction

Unlike for other solid tumors, biopsy has not played an important role in the diagnosis of renal tumors and it was not included in diagnostic algorithms [1, 2]. Classically, a biopsy was indicated in those cases where there was a reasonable clinical doubt as to the origin of the tumor (primary renal or metastases of other cancers) or when the differential diagnosis was between a renal cell carcinoma and other causes of a renal mass (e.g. lymphoma or infection). However, in the most recent version of the American Urological Association (AUA) guidelines, biopsies are also recommended in patients with a wide range of treatment options varying from observation to surgery [1]. Another indication for a renal mass biopsy is the presence of metastatic disease, where there is a role for targeted therapy such as immunotherapy or angiogenesis inhibitors. Studies have shown that the determination of renal cell carcinoma (RCC) subtype is of vital importance since there are different treatment strategies for clear-cell RCC and nonclear-cell RCC [3].

Surveys among urologists show that the majority do not perform a renal mass biopsy even in cases of indeterminate lesions [4, 5]. The main reasons given for this were the presence of false negative results and that biopsy in most cases will not change management. A major concern was the low predictive negative value of the biopsy. The post-test probability of a diagnosis of RCC in cases with a negative renal mass biopsy has been estimated at 18% [6]. A recent comprehensive review shows that in approximately three-quarters of cases with nondiagnostic biopsies, malignancy is diagnosed at re-biopsy or surgery [7].

Currently, due to the profuse use of abdominal imaging, up to 70% of kidney tumors are accidentally discovered before symptoms arise [8, 9]. The mean size of tumors that are operated on has steadily decreased in the last two decades [10–12] and the absolute number of small renal masses (≤4 cm) diagnosed has increased, although their relative impact on the total number of tumors is still unknown. Additionally, pathologic assessment of small renal masses has evolved and the classical cut-off of 3 cm to distinguish a renal carcinoma from a benign adenoma is no longer valid. While 20 years ago every renal mass smaller than 3 cm was considered as benign, with increasing knowledge, identification of the different types of RCC and broad application of immunohistochemistry (IHC) techniques, it is known that a high percentage of these small renal masses are carcinomas [13].

The real problem does not arise in the differential diagnosis of large renal masses, where cross-sectional imaging has been proven to have a high accuracy, but in the proper assessment and differentiation of the small renal masses [13, 14]. Doubts remain about the aggressiveness of small renal masses. In an autopsy study between 1984 and 1995 it was demonstrated that 47% of all renal tumors was not clinically known. The stages of the nonclinically diagnosed tumors were mainly of T1 and T2 [9]. Another autopsy study showed a decrease in the size of nonclinically discovered renal tumors found at autopsy from 4.63 to 1.65 cm between 1955–1960 and 1991–2001, respectively [15].

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Surgical contemporary series show a benign tumor incidence of 20–30% among small renal masses and this incidence is inversely proportional to size [13, 14, 16]. A definitive cut-off for aggressiveness can be established at the 3 cm diameter. While bias cannot be ruled out in the surgical series, mainly from the inclusion of cysts with different Bosniak grades, the percentage of benign masses in this size range is too high to justify an intervention without histologic confirmation of malignancy or a reasonable doubt that the mass is benign. However, interventional policies based on surgical excellence might not be ideal for the evaluation of the potential use of a test in the wider medical community.

Furthermore, partial nephrectomy, which should be considered the gold standard for small renal masses, is unfortunately underused [17], leading to overtreatment of small benign masses [18]. At the other extreme of the management spectrum, ablation or surveillance, small renal masses deserve to be biopsied for diagnosis and follow-up purposes.

Biopsy nomenclature

Before reviewing the results of renal mass biopsy, it is necessary to critically assess the nomenclature. The accuracy of a diagnostic test is measured by its sensitivity and specificity. Strictly speaking, only those studies with histologic confirmation on a surgical specimen can give accurate figures for these.

Basically, when a renal tumor is evaluated, a biopsy can deliver one of two results: diagnostic (benign or malignant) or nondiagnostic (Figure 110.1). When the biopsy is diagnostic, other characteristics such as histopathologic type and grade can also be assessed.

There are different reasons for a nondiagnostic biopsy (Table 110.1). Conceptually a failed biopsy means that there is no tumor tissue available for assessment in the biopsy specimen, although other types of tissue might be present in the sample. The reason for a failed biopsy could be a technical failure of the puncture method (e.g. misfire or malfunctioning of the biopsy gun) or an incorrect sampling. Incorrect sampling is sometimes unavoidable due to the nature of the renal tumors: these may contain necrotic and fibrotic tissue, or be mixed in nature with solid and cystic components. Also, the presence of normal renal tissue implicates that the sampling is incorrect as very few renal masses are composed of normal renal tissue. The presence of fibrotic, inflammatory, fatty or necrotic tissue in the specimen will mean that a diagnosis cannot be made from it.

In indeterminate (or inconclusive) biopsies, tumor tissue is present in the biopsy specimen but it is impos-

Table 110.1 Nomenclature of the nondiagnostic biopsies based on the sample findings, and reasons leading to a nondiagnostic result.

Nomenclature	Tissue in the sample	Reasons
Failed biopsy	Absence of tumor cells (other types of tissue may be present)	Technical failure (e.g. misfiring) Erroneous sampling (e.g. normal kidney, fibrosis, fat, inflammation, necrosis, blood)
Indeterminate (inconclusive) biopsy	Impossibility to differentiate benign from malignant cells	Insufficient cells Morphologic overlap Cellular heterogeneity

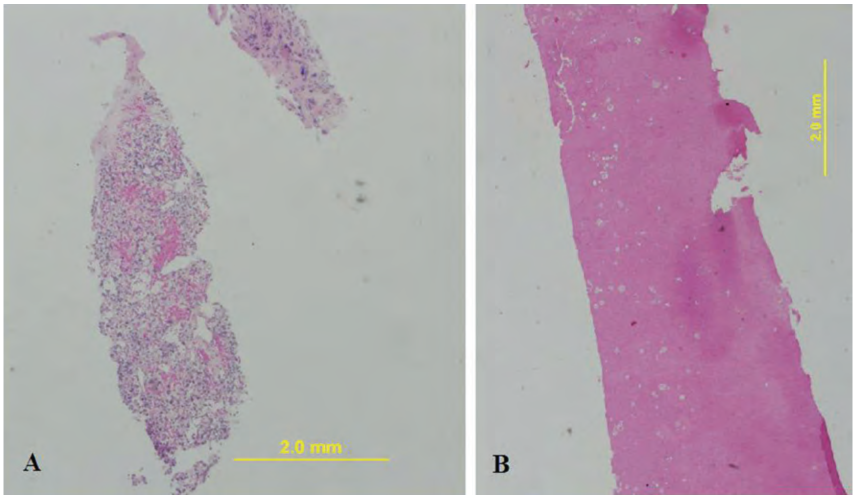

Figure 110.1 (A) Diagnostic and (B) nondiagnostic (fibrin) core biopsy of a renal tumor.

sible to determine the biology of the cells. In this case, IHC techniques may be of help if enough tissue is available.

Definitions in the literature are confusing and a certain overlap between failed, incorrect sampling and indeterminate biopsies is unavoidable. Diagnostic yield is the rate at which biopsies establish a diagnosis. Diagnostic biopsies can also give false results, both positive and negative, and the sum of these is the rate of inaccurate biopsies. Accuracy is then calculated from the total number of diagnostic biopsies.

Besides the technical failures and the indeterminate biopsies, benign nontumoral conditions (e.g. normal renal parenchyma) found in the biopsy specimen will be classed as diagnostic by some and nondiagnostic by others. Variations in results are conditioned by the lack of standardization of the taxonomy but also by the well-proven interobserver variability among pathologist. Interobserver variability may be responsible for an up to 11% differences in the rate of nondiagnostic biopsy, both for core biopsy (CB) and fine needle aspiration (FNA) [6, 19–21].

Renal biopsy technique

There are two aspects when considering the technique of percutaneous renal biopsy: the type of image guidance and the type of biopsy performed [CB or cytologic aspiration (FNA)].

Image guidance

Most renal biopsies are performed percutaneously and are supported by image guidance using computed tomography (CT) or ultrasound. The biopsies are normally performed under local anesthesia in an outpatient setting. When performing biopsies during surgery or *ex vivo*, direct vision can be used. Compared with *ex vivo* renal mass biopsies, recent studies with imaging-guided percutaneous renal mass biopsies have shown better outcomes in terms of failed or indeterminate biopsies [22]. The outcomes of biopsies performed using ultrasound, CT or magnetic resonance imaging (MRI) are similar and therefore the choice between the radiologic modalities should be made on other grounds [23–26]. MRI-guided biopsy is not widespread as it entails the use of the more costly nonferromagnetic needles [23].

Ultrasound

Ultrasound guidance appears to have several advantages: it is generally available and less costly, results in less radiation, most urologists can perform it themselves, provides realtime and multiplanar imaging, and the device is portable. However, not all lesions can be visualized on ultrasound and anatomic structures, such as the ribs, and gas can obscure visibility. Finally, performing ultrasound-guided renal biopsies requires a significant learning curve. Visualization of the needle tip on ultrasound can be improved by several methods [27]. Biopsies can be performed using a guide or "freehand."

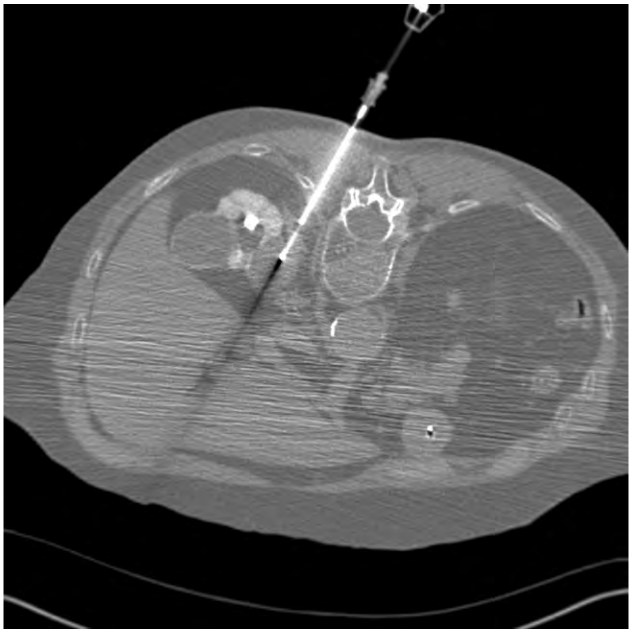

Figure 110.2 CT-guided biopsy of a renal mass in the right kidney (patient in the prone position).

Computed tomography (Figure 110.2)

Advantages of CT guidance are that most renal tumors can be identified after contrast injection and that the puncture of intratumoral changes can be avoided to optimize the results of the biopsy (e.g. hemorrhagic zones that can result in necrosis). Adjacent organs can be optimally identified and the technique is easier to master. These advantages are even more significant in obese patients. However, realtime CT imaging is potentially hazardous for the investigator and patient due to radiation exposure. It is possible due to manipulation of the needle that the biopsy is performed outside the selected target, resulting in false-negative of nondiagnostic biopsies.

Type of biopsy

Fine needle aspiration

FNA or cytologic aspiration is performed under image guidance. When the patient is properly positioned, the

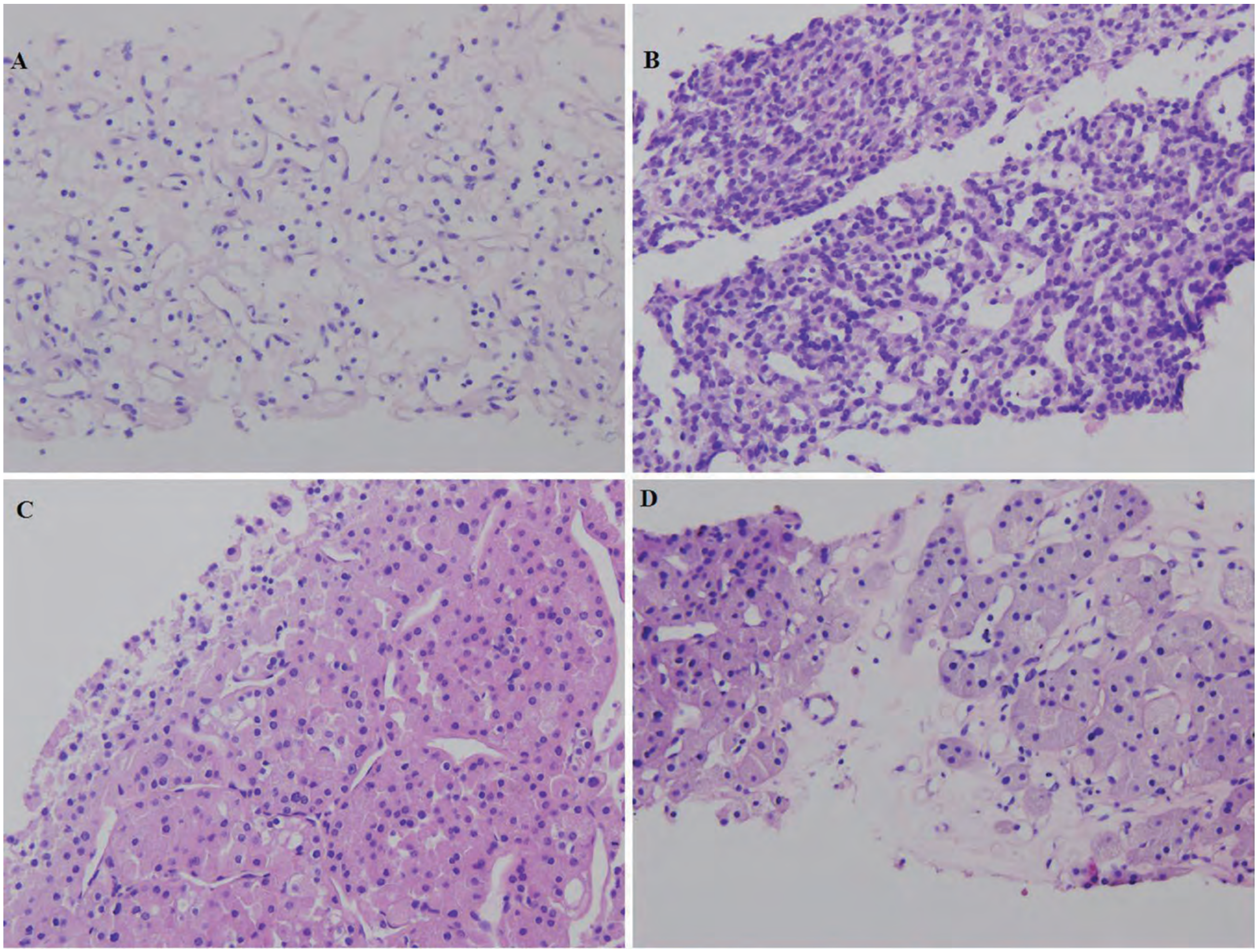

Figure 110.3 Histopathologic core biopsy samples (H&E staining) of different subtypes of renal cell carcinoma and oncocytoma: (A) clear cell RCC; (B) papillary RCC; (C) chromophobe RCC; (D) oncocytoma.

most suitable needle path is chosen. A guiding cannula is advanced onto the tumor surface and the needle is passed through the cannula into the tumor, trying to avoid possible necrotic areas. The cannula is used to avoid direct contact between the tumor and surrounding retroperitoneal tissue, decreasing the risk of tract seeding [27, 28]. The needle is then moved back and forth within the tumor to collect the cells. Traditionally, negative pressure with a syringe is applied on the needle in order to collect more cells. Another method that does not use negative pressure is Zajelda's fine needle capillary technique. This tends to reduce the amount of blood in the sample, but may result in fewer cellular smears [23]. If a CB and FNA are to be performed in the same session, the FNA should be performed first, to reduce the amount of blood in the cytologic specimen [23]. The aspirate is placed on slides and smeared directly. An on-site cytotechnologist can immediately determine the quality of the specimen, which should increase the rate of diagnostic FNAs and subsequent CBs since correct needle placement is ensured [23].

Cytologic examination can provide cytologic detail that is sometimes superior to that seen in CBs (Figure 110.3). FNA samples can be used to prepare cell blocks which are helpful to identify specific histoarchitectural features and to perform IHC studies. A recent study has shown excellent results with an improved agar microscopy which comprises processing the aspirate of FNA by centrifuging it in agar. This technique results in concentrated cell blocks composed of fragments and loose cells that are suitable for slicing and subsequent histologic interpretation with IHC [29]. Additional testing, such as flow cytometry, fluorescent *in situ* hybridization (FISH), apoptosis assays, and picrosius red F3BA staining, are also possible with FNA [23].

Core biopsy

A CB is performed with a hollow needle, allowing it to remove small but solid samples of tissue suitable for fixation and histologic examination (Figure 110.4). The needle has a cutting edge that allows tissue samples

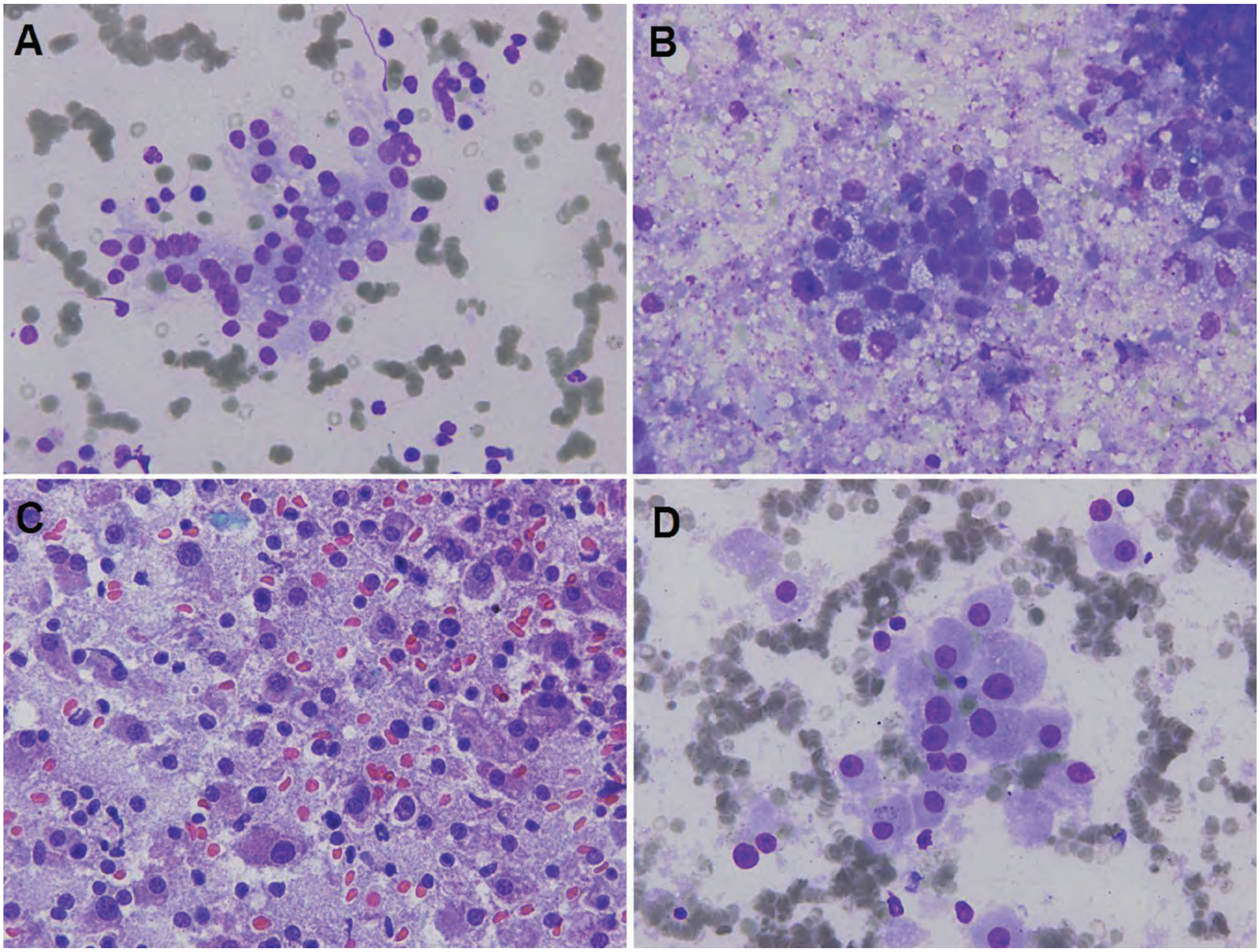

Figure 110.4 Fine needle aspiration biopsy samples (Giemsa staining) of different subtypes of RCC and oncocytoma: (A) clear cell RCC; (B) papillary RCC; (C) chromophobe RCC; (D) oncocytoma.

larger than 1 cm in length to be removed. Thicker needles than for FNAs are used (17G or 18G). The risk of complications does not increase with the use of these needles [25, 30–39]. Usually, 18G or 17G needles are used with an automatic biopsy gun to obtain tissue samples of 15–22 mm in length. The quality of the core should be checked at the time of the biopsy, in order to repeat it if there are doubts about its quality.

Technical considerations

There are technical considerations with both FNA and CB to improve the quality of the sampling and to maximize the results.

The choice of radiologic imaging depends on tumor location, size, access feasibility, visibility and individual preference. Imaging is used to avoid areas suggestive of pathologic necrosis or cystic areas. The same considerations apply to the choice of biopsy type, FNA or CB. In general higher accuracy has been shown for CB, although experienced groups achieve the same results with FNA [40]. The ideal is to perform both types of biopsy during the same procedure.

Larger needles have shown better results in terms of sample quality, and there is no increased risk for complications when comparing 18G to 22G needles [23, 25, 29, 36–39] (Figure 110.5). Most recently, Breda *et al*. compared the *ex vivo* performance of three distinct needles (14G, 18G, and 20G) in a blinded study [41]. One core biopsy was obtained with each needle from 31 tumors. Biopsies were analyzed by H&E and a standard IHC panel. All the biopsies performed with the 14G and 18G needles provided sufficient tissue for diagnosis, whereas the technical failure rate for the 20G needle was 14%. Sensitivity to distinguish between benign and malignant tumor was high for the three needle calibers, but specificity was lower for the 20G needle. Histologic accuracy was 92%, 97% and 81% for 14G, 18G, and 20G needles, respectively. Grade accuracy was consistently low for the three needles and in the range 40–56%. These

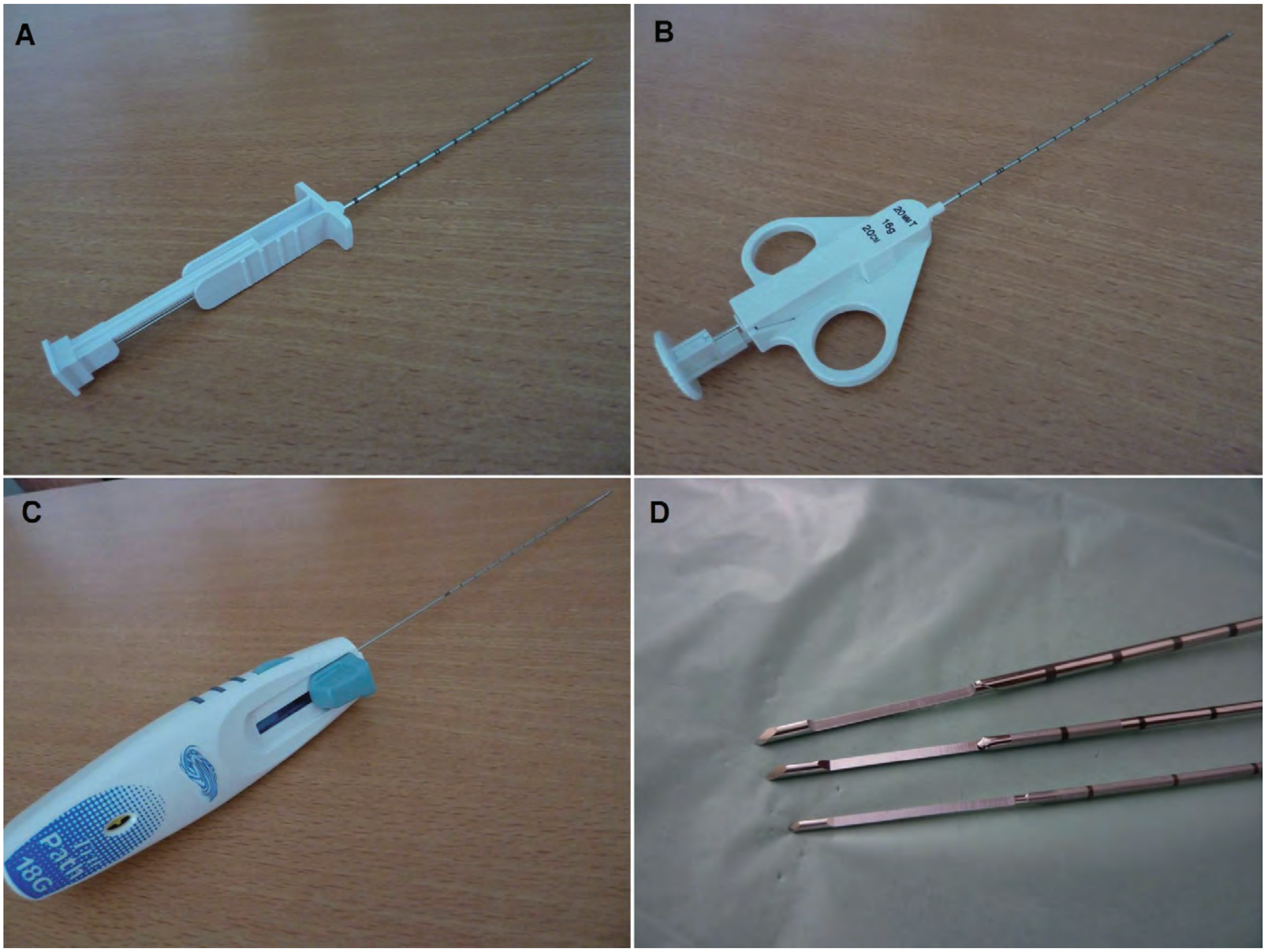

Figure 110.5 Core biopsy needles: (A) manual 14G needle; (B) semi-automatic 16G needle; (C) fully automatic 18G needle. (D) Needle tips of the 14G, 16G, and 18G biopsy needles (top to bottom). All cores obtained are between 18 and 20 mm in length.

authors concluded that at least one core biopsy with an 18G needle offers the highest accuracy in histologic diagnosis [41]. The change to thicker needles could be at least partly responsible for the increasing accuracy and decreasing failure rate of the biopsies [22].

Different type of needles are available to perform a CB. Automatic Tru-Cut needles are easier to manage than the original manual Tru-Cut needles.

There are no studies in the literature comparing the results for different number of samples. However, the number of CBs advised in the literature is at least two [22, 23, 33]. For FNA, as many passes as necessary should be performed to ensure a diagnostic smear. As mentioned above, ideally the cytologist should prepare the smear directly after puncturing ("on site") and examine it immediately to ensure the presence of cells and to give the opportunity to repeat the cytologic aspiration if necessary.

In both CB and FNA it is recommended to use a cannula that is wider than the biopsy needle to be used. This cannula is advanced under imaging onto the surface of the tumor and remains stable during the whole procedure. The biopsy needle is advanced through the cannula, which allows a number of passes or biopsies to be performed without the risk of contamination or seeding, and avoids manipulation of the chosen tract.

Tumor size does affect the results of the biopsy. Since larger tumors more frequently have central necrosis, it is recommended to perform a peripheral and a central biopsy in tumors smaller than 4 cm and two peripheral biopsies for tumors larger than 4 cm [42].

Although bleeding complications are rare (see below), coagulation abnormalities should be corrected prior to biopsy, anticoagulants should be stopped when possible, and some hours of rest are recommended after biopsy.

CBs are best preserved in formalin until fixation and analysis.

Complications

Potential complications of percutaneous renal biopsies are bleeding, tumor seeding along the needle tract, arteriovenous fistula, infection, and pneumothorax.

There is enough evidence to affirm that minor complications are infrequent, occurring in less than 5% of all biopsies performed for renal masses. Catastrophic complications are extremely rare and mortality has not been described in the recent literature [22]. The most frequent complication is hemorrhage [22, 43, 44]. There are controversial reports on the correlation between needle size and rate of complications [39, 45, 46]. The correlation is highest when 15G needles are compared with 21G needles; however, as mentioned above there is no significant difference in complication rate when 18G and 21G needles are compared [46].

The most feared complication of renal biopsies is tumor seeding. However, in all recent series (from 1994 onwards) of renal tumor biopsy, no cases of tract seeding have been reported. This might be explained by the widespread use of a guiding cannula for renal biopsy [23, 47]. Urothelial carcinomas have a higher tendency to seed along the tract than RCCs. Therefore, when urothelial cell carcinoma is suspected, a percutaneous biopsy for diagnostic purposes is not recommended [47, 48].

Other complications occur very rarely. An arteriovenous fistula should be considered in cases of persistent bleeding [49]. When the renal biopsy is performed by a posterior approach, pneumothorax has been reported in 14–29% of cases, although clinically significant pneumothorax is uncommon (<1%) [44, 48]. To further minimize the risk of a pneumothorax, the puncture should be performed in expiration and the needle should be positioned subcostally. Some upper pole tumors can be punctured using the paravertebral approach, which involves the injection of saline in the paravertebral space to displace the pleura laterally [50].

There is no evidence that a renal mass biopsy can complicate a subsequent partial or radical nephrectomy [39, 51, 52].

Results

From the 1970s onwards, many studies have been performed on the diagnostic accuracy of renal mass biopsy. Early studies focused on cytologic aspiration with Chiba needles, but the incorporation of automatic fine CB needles minimized trauma and allowed core samples to be obtained that were easier to analyze.

In 2008 Lane *et al*. published an extensive review on the subject [22]. They divided the studies chronologically between those conducted before and from 2001 onwards. Before 2001, 27 studies were considered, in two of which "*ex vivo*" tumor biopsy was performed. After 2001, seven clinical studies and three *ex vivo* studies were considered. An overall diagnostic accuracy of 88.9% was reported for the earlier period (including *ex vivo* biopsies) and a 96% clinical accuracy (excluding *ex vivo* biopsies) for the later period. Although no statistical comparison was available, these figures suggest an improving trend in the diagnostic performance of the biopsy. Whether a 7% difference in accuracy is of clinical significance remains unknown, but it is worthwhile. Furthermore, false-negative and -positive rates both decreased between periods.

Accuracy of the biopsy was calculated based on the number of successful biopsies. Biopsy failures defined as "the inability to obtain an amount of tissue sufficient for diagnosis" were excluded from the accuracy assessment. Consequently, in clinical practice, the physician has to be aware that diagnostic yield is different from accuracy, as the biopsy failures accounted still for 9% and 5.2% for the periods before 2001 and from 2001 onwards, respectively. Indeterminate biopsies were included in the accuracy assessment in the review. However, an indeterminate biopsy is in fact a nondiagnostic biopsy. The sum of technical failures plus indeterminate biopsies ("no definitive diagnosis possible using the available techniques") was 19% and 10% in the respective periods. In summary, biopsy has a high accuracy in the modern era, but nondiagnostic biopsies still account for an overall 10% in general series irrespective of the tumor size.

When considering these results, some limitations of the review, most of which were pointed out by the authors, must be mentioned. First, the studies included in this review compared the biopsy results to numerous different gold standards. These index tests varied from pathologic examination of the specimen after surgical excision to radiologic follow-up of nonextirpated tumors [7]. For example, in the period before 2001, surgery and consequently surgical specimen available for comparison was noted in only 49.5% of the cases previously biopsied, excluding the *ex vivo* biopsy studies for which a surgical specimen was obviously available in all cases. The number of cases with surgical specimen available for comparison increased to 54% in the second study period. Together with the recent knowledge that the lack of radiologic growth does not necessarily mean absence of malignancy [53], this means that the results of the biopsies were compared to a strict index test in only half of the cases.

Second, the percentage of pathologically confirmed renal carcinomas was 70.5% before 2001 and 82% from 2001 onwards, which could suggest that selection criteria based on imaging could have improved over time.

Third, heterogeneity among series in both periods in terms of selection criteria, technical issues (e.g. needle used, histopathologic type of biopsy), and the different number of cases included precludes sound statistical comparison.

All the above mentioned reasons may be sources of bias in the interpretation of the analysis, and overestimation of the biopsy accuracy cannot be ruled out, but neither can the improving trend be denied.

In an attempt to clarify the results, we further examined those series where pathologic confirmation was obtained in the form of a surgical specimen in 100% of cases, whether *ex vivo* or in the clinical setting, including with a preoperative percutaneous biopsy. Results of biopsy of small renal masses are also considered separately, as results from general series may not be extrapolatable to these masses.

Ex vivo biopsies

Several studies have evaluated the accuracy of the *ex vivo* (in bench) biopsy for the diagnosis of renal tumors [6, 20, 21, 30, 31, 41, 42, 54, 55]. The accuracy of surgical excision (nephrectomy or partial nephrectomy) biopsies taken under direct vision were compared to the definitive pathologic diagnostic of the surgical specimen in 100% of the cases. In most of the studies pathologists evaluating the biopsy were blinded to the definitive histopathologic results.

Ex vivo CBs were sufficiently accurate to be able to differentiate between a malignant and a benign renal mass (Table 110.2). Overall accuracy varied from 72% to 90%, and was not lower for FNAs [20]. The rate of nondiagnostic biopsies varied from 2% to 20% with a trend to be higher than in the modern percutaneous biopsy studies [22]. Using the same nomenclature as in the article by Lane *et al.* [22] is used, Kummerlin *et al*. described a rate of failed biopsies (called *nondiagnostic*) between 8% and 16% for the five pathologists involved in the study, and a rate of indeterminate biopsies (called *nonconclusive*) between 0% and 8% [19]. This fact may be explained by the lack of visualization of the entire tumor, as can occur during imaging or in the absence of needle stabilization during percutaneous puncture. Subtype differentiation between oncocytoma and chromophobe RCC remains problematic (see Figures 110.3 and 110.4). Kummerlin *et al*. found a good overall accuracy for *ex vivo* FNA in differentiating between malignant and benign masses [18, 20]. However, again there was a substantial interobserver variation regarding the subtype differentiation other than for clear-cell RCC.

When interpreting the results of in-bench biopsy studies, it has to be taken into account that this *ex vivo* setting is only partially comparable to clinical practice, where percutaneous biopsies will be the standard.

Percutaneous biopsy compared with 100% surgical specimens

The number of studies on the accuracy of percutaneous renal mass biopsy based on 100% comparison of the preoperative samples with the surgical specimen is very low.

Before 2001 only three such studies were identified in the review of Lane *et al.* [56–58]. In these studies accuracy for the diagnosis of RCC varied from 40% to 94%; the rate of biopsy failures varied from 0% to 22% and the rate of indeterminate biopsies from 4.3% to 36%. False positives were almost nonexistent (0–2.2%), but false negatives accounted for 0–24%. These results are clearly insufficient to justify the systematic use of percutaneous biopsy in the diagnostic setting. However, comparison with modern data is precluded as different needles, mostly 21G and 22G, were used, and in two of those studies biopsy was guided by old ultrasound devices.

After 2001, only three more reports are available in the literature in which the percutaneous renal mass biopsy has been compared in all cases with the surgical specimen [54, 59, 60] (Table 110.3).The sensitivity of percutaneous core biopsy to detect malignancy proven at surgical specimen varies from 91.4% to 93.5% and the negative predictive value from 50% to 81.3%. The rate of nondiagnostic biopsies was very low in these three modern studies, in the range of 2.4–7.1%, although in some cases a repeat biopsy was necessary to reach a diagnosis. Correct RCC subtype determination varied from 77.5% to 91% and correct Fuhrman nuclear grade from 51.5% to 76%, with the grade mainly being underestimated on CB.

Biopsy in small renal mass

The performance of renal mass biopsies in small renal masses (SRMs; ≤4 cm) is of utmost importance for a number of reasons. There is a high percentage of benign masses among the small renal tumors [13, 61], radiologic distinction between malignant and benign may be extremely difficult in this size range [14], and in spite of the low biologic potential of small RCC, some will be of high grade [16, 18]. The clinical scenario becomes even more complicated as a considerable number of those SRMs are accidentally found in older patients with comorbidity. Especially in SRMs, a preoperative histologic diagnosis may lead to a change in management.

In general, the sensitivity of renal biopsy in SRM is lower when compared with general series on renal biopsy (including all tumor sizes). The biopsy failure rate increases in SRMs. A rate of biopsy failure as high as 37% has been reported in renal masses smaller than 3 cm versus 9% in tumors larger than 3 cm [52].

Table 110.4 gives an overview of published studies on biopsies in SRM. As expected, biopsy results for SRMs are less accurate than in larger masses, with histologic confirmation by means of surgical specimen in 30–78% of cases [22]. The rate of nondiagnostic biopsies is also

Table 110.2 Results of *ex vivo* biopsies. Pathologic surgical specimen available in all cases.

	Mean or median tumor size [cm (range)]	Number of tumors	Accuracy (biology)	Nondiagnostic biopsies (*)	Accuracy RCC type	Accuracy RCC grade
Nurmi *et al.* (1984) [55]	–	150	100%	2%	–	76%[a]
Dechet *et al.* (1999) [21][b]	4.6 (1–18)	106	Overall 76–80% Sensitivity 77–84% Specificity 60–73% PPV 94–96% NPV 69–73%	11–17%	NA	NA
Dechet *et al.* (2003) [6][b]	NR	100	Overall 72–77% Sensitivity 81–83% Specificity 33–60%	20–21%	NA	NA
Wunderlich *et al.* (2005) [42][c]	4.97 (2–20)	50	98% (diagnostic yield)	2%	70% (diagnostic yield when tumor origin definable)	83% (diagnostic yield when tumor origin definable)
Barocas *et al.* (2006) [30]	5.3 (1.1–15.5)	77	Overall 90% Sensitivity 87–100%[d] Specificity 96.5–96.5%[d] PPV 96.4–96.9%[d] NPV 87.5–100%[d]	4%	90%	–
Barocas *et al.* (2007) [31]	4.5 (1.3–11.3)	36	69–79%[e]	14%	87%	NA
Kummerlin *et al.* (2008) [19][f]	5.5 (2–12)	62	Overall 77–90% Sensitivity 79–100% Specificity 100% PPV 100% NPV 29–100%	8–19%	NA	NA
Kummerlin *et al.* (2009) [20][g]	5.5 (2–12)	66	Overall 73–91% Sensitivity 72–97%[h] Specificity 63–100%[h] PPV 93–100%[h] NPV 24–75%[h]	3–14%	NA	NA
Breda *et al.* (2010) [41][i]	6.3 (0.8–17)	31	Sensitivity 96–100% Specificity 67–75% PPV 96% NPV 75–100%	0% (14G needle) 0%(18G needle) 16% (20G needle)	92% (14G needle) 97% (18G needle) 81% (20G needle)	48% (14G needle) 40% (18G needle) 56% (20G needle)

[*] Nondiagnostic biopsies includes failed biopsies and indeterminate biopsies.
[a] Grade as low, intermediate and high.
[b] Two pathologists independently evaluated all samples.
[c] Five core biopsies per tumor.
[d] Addition of molecular diagnosis increased sensitivity and NPV.
[e] By adding FISH to conventional H&E staining.
[f] Core biopsy evaluated independently by five pathologists.
[g] FNA evaluated independently by five pathologists.
[h] For malignant tumors.
[i] Three different biopsy needle calibers compared (14G, 18G, and 20G).
NA, not assessed; NR, not reported; PPV, positive predictive value; NPV, negative predictive value.

Table 110.3 Modern series on percutaneous renal mass biopsy with pathological confirmation (surgical specimen) in all cases.

	Number of tumors	Mean tumor size [cm (range)]	Guidance/ needle	Type biopsy/ number of samples	Nondiagnostic biopsies*	Accuracy	Accuracy histologic type	Accuracy grade
Schmidbauer *et al*. (2008) [60]	78	3.9 (0.8–9)	CT/18G	CB/2–3	3%	Sensitivity 95.2% Specificity 100% PPV 100% NPV 81.3%	91%	76%
Blumenfeld *et al*. (2010) [54]	81	5.3 (1–17)	US–CT/18G	CB/at least 2	2.5%	NR	88%	43%
Sofikerim *et al*. (2010) [59]	42	6.4 (2.5–14)	US/18G	CB/2	7.2%[a]	90% for biology Sensitivity 91.4% Specificity 60% PPV 94.1% NPV 50%	77.5%	51.5%

[*] Nondiagnostic biopsy includes failed and indeterminate biopsies.
[a] Nondiagnostic rate lowered to 4.7% after repeated biopsy.
CT, computed tomography; US, ultrasound; CB, core biopsy; NR, not reported.

Table 110.4 Results of biopsies in small renal masses. All included studies are on masses ≤4 cm with the exception of Shannon *et al.* [66] (modified from Laguna *et al.* [7]).

	Tumor size (cm)	Guidance	Number of tumors	Nondiagnostic biopsies*	Pathologic confirmation**	Accuracy
Neuzillet *et al*. (2004) [51]	2.8[a]	CT	88	9%	70.4%	90%
Rybikowski *et al*. (2008) [63]	≤ 4	CT	66	18%	78%	91% for malignant 57% for benign
Thuillier *et al*. (2008) [64]	2.5[a]	NS	53	23%	60%	Sensibility 96% Specificity 100%
Wang *et al*. (2008) [65]	2.7[a]	CT/US	110	9%	34%	100%
Volpe *et al*. (2008) [62]	2.4[b]	CT/US	100	16%	20%	84%
Shannon *et al*. (2008) [66]	2.9[b] (<5)	CT	222	22%	59%	100% for biology 98% for subtype
Kummerlin *et al*. (2009) [20]	3.5[b]	In bench[c]	30	7–17%[c]	100%	Overall accuracy 67–87%[c] (67–93% for malignant and 33–100% for benign)[c]

[*] Includes failed and indeterminate biopsies.
[**] Cases with surgical specimen available.
[a] Mean size.
[b] Median size.
[c] Five pathologists' independent results.
CT, Computed tomography; US, ultrasound; NS, not specified.

higher in SRM, either because of technical failure or because of indeterminate results.

It was demonstrated that when the result of a biopsy is malignant, subtype determination is possible in 93% of the biopsies; however, IHC is necessary in a substantial number of cases. Concordance with the surgical specimen is high (91–100%) [62, 63]. Fuhrman nuclear grade was correct in 68%, with a lower concordance than for subtype (60–100%), as was the case in larger renal masses [62–64].

Accuracy for histology and grade

Kidney tumors are known to show intratumoral heterogeneity and therefore subtype identification can be misleading when biopsies are assessed. However, in the modern series an overall accuracy of 94% in identifying the correct histologic subtype was reported [22]. Similar results for grade accuracy have been reported for SRMs, although IHC was necessary in most cases [62].

One of the major problems in differentiating subtypes of RCC is the distinction between oncocytoma and chromophobe RCC, since hybrid tumors containing areas of benign oncocytoma and malignant chromophobe RCC exist [60]. This issue remains a challenge for the pathologist, especially when limited tissue is available, as is the case with biopsies. New auxiliary techniques, such as genetic profiling, polymerase chain reaction (PCR), and FISH are under development to distinguish chromophobe RCC, oncocytomas, and other subtypes of RCC with more accuracy [32, 33, 67, 68].

Heterogeneity of renal tumors is also hindering correct determination of Fuhrman's nuclear grade by biopsy. In two large recent series, Fuhrman's nuclear grade was correctly determined in 70% [51] and 83% [42] respectively. In all the discordant cases, the actual grade found in postoperative pathology was within one grade of the grade found at biopsy. A higher accuracy (76–100%) is obtained when the nuclear grade of tumors is grouped into "low grade" (Fuhrman I–II) and "'high grade" (Fuhrman III–IV) [51, 52].

Biopsy during thermal ablation

When performing thermal ablation of small renal tumors, such as cryoablation (CA) or radiofrequency ablation (RFA), information on the pathology of the ablated mass can only be gained through biopsy of the tumor, since the specimen is not extirpated. This information has not only diagnostic purposes but may impact follow-up policy. An additional use of biopsies in the frame of ablation therapy is in determining the presence of residual tumor.

Two recent meta-analysis have compared CA with RFA [69] and percutaneous ablation with surgical ablation, including laparoscopy [70]. Biopsy of the mass was performed in 82.3% of the CA, in 62.2% of the RFA, in 84% of the percutaneous procedures and in 88 % of the surgically assisted ablations [69, 70]. Overall, between 54% and 64% of the biopsies confirmed RCC, 12.7% showed benign pathology and 33.5% had unknown of undetermined pathology [69]. With the limitations derived from the lack of well designed comparative studies it becomes evident that biopsy of the tumors is widely adopted during ablation treatments but in the case of RFA where still 40% of the patients are treated without information on tumor biology.

The rate of nondiagnostic biopsy varies from 0% to 23% in those series of percutaneous ablation [71–74] and from 0% to 30% when tumor biopsy is performed during laparoscopic ablation [75–80]. These figures are similar to the nondiagnostic rates described for SRMs (see Table 110.4) as the tumors treated by ablation are in this size range. At least during laparoscopy-assisted ablation, modification of the biopsy technique, by activating the firing mechanism of the biopsy gun externally to the target tissue, led to a higher diagnostic yield in a small clinical series [77]. The criteria classifying a biopsy as nondiagnostic or benign varies between groups, which may explain the broad range of nondiagnostic or benign results. As an example, normal renal tissue, fibrotic tissue or necrotic tissue are distinctly classed as benign by some and nondiagnostic by others [78, 80]. In fact, the stricter the nondiagnostic criteria are, the higher the nondiagnostic rate of the biopsy.

Tumor biopsies can also be taken immediately after ablation to minimize risk of bleeding or tract seeding. In this situation, the pathologist can identify RCC architecture both after RFA and CA and the diagnostic yield of the preablation and immediate postablation biopsies is not statistically different [81–83].

Success after ablation therapy is mainly determined using cross-sectional imaging with contrast. Lack of contrast enhancement indicates absence of tumor recurrence [84]. However, the presence of viable tumors in the ablated area is not completely ruled out by the lack of enhancement on CT or MRI [85]. Therefore, some centers have performed an additional postablation biopsy to assess the success of the ablation. A study on the correlation of radiographic imaging and histopathology showed that in 24% of patients treated by RFA, the 6-month postablation biopsy showed viable renal cancer cells even though there were no signs of radiologic enhancement at that time [86]. The 6-months postcryoablation biopsy was consistently negative in all nonenhancing masses. Therefore, the sensitivity of nodular enhancement at 6 months after RFA to detect a positive biopsy was only 38.4%, with a specificity of 91.3%. The results for cryoablation were superior, with a sensitivity and specificity of 77.8% and 95.1%, respectively. In contrast, a study on RFA lesion biopsy more than 1 year after ablation showed no vital lesion [87]. It is therefore advisable to use NADH or other oxidative stress stains when assessing biopsy after ablation [88].

Additional pathologic methods

RCC subtyping was originally performed using a light microscope and standard H&E staining. The diagnostic accuracy in differentiating benign from malignant renal mass is substantial, but for determining RCC subtypes the accuracy is lower, since complex and overlapping morphologic features exist. As described earlier, this results in the interobserver and intraobserver variability of subtyping [19, 20].

For a long time research to improve subtyping of renal tumors had no priority since there were no clinical consequences. However, there has been interest in subtype determination of RCC following the incorporation in clinical practice of targeted therapies. Correct determination of RCC subtype can be of capital importance since paradigms for specific RCC subtypes may not apply to other subtypes. Therefore, a more accurate differentiation of RCC subtypes is desirable.

Differences among RCC subtypes at the DNA or RNA and the protein level have been explored in order to improve the accuracy of subtype differentiation. Although different subtypes of RCC show overlapping histologic features they are biologically distinct. This is obvious when the cytogenetic abnormalities of different subtypes are observed: different subtypes have characteristic abnormalities, such as chromosome 3p aberrations in clear-cell RCC and trisomy 17 in chromophobe RCC [89]. These characteristic differences imply that the different subtypes are distinguishable by mapping this genetic expression.

One method to perform a molecular gene profiling analysis is DNA microarray. This has shown differences in gene expression profiles between subtypes of RCC and therefore it differentiates between the histologic subtypes of RCC [90–92]. By analyzing the mRNA expression ratios of different genes in different subtypes of RCC, the individual subtypes can be differentiated: high CA9 expression in clear-cell RCC, AMACR in papillary RCC, and CLCNKB in chromophobe RCC and oncocytoma [93] which facilitates a molecular diagnostic algorithm. It has been demonstrated that renal masses can be accurately classified on CBs using a combination of histopathology and molecular gene profiling analysis [30].

In order to obtain sufficient material for investigation, the genetic material harvested with percutaneous biopsy should be amplified by PCR [23, 30].

Another auxiliary technique for subtype differentiation is IHC, which localizes specific antigens or proteins in a tissue sample by binding the antigens with labeled antibodies. The formed antigen–antibody complex can be visualized by (fluorescent) staining and therefore the presence of the antigen can be demonstrated.

Several antigens have been found to be useful as a marker for subtype determination of RCC, and they are currently used in combination with histologic investigation to improve the diagnostic accuracy. It is likely that in the near future these techniques will contribute more to the diagnostic process [94–96].

Conclusions and recommendations

There is an increasing interest and trend to incorporate the percutaneous biopsy of a renal mass into the diagnostic algorithm of small renal tumors, when treatment depends on histologic subtype determination, and for ablative procedures. CB is more commonly performed than FNA. Complications are rare and mostly of low grade.

Modern series on percutaneous biopsy of renal masses show a high accuracy and a lower rate of failed or undetermined biopsies than older series. Although still scarce, those recent series with pathologic confirmation by means of surgical specimen support these encouraging results. The accuracy of histologic subtype determination in the biopsy specimen may be up to 94% and of Furman's grade up to 70%. Oncocytic features may overlap with those of chromophobe RCC.

However, when considering a percutaneous biopsy in an SRM, there needs to be an awareness that accuracy will be inferior to that reported in general series. The overall rate of nondiagnostic biopsy, either failed or inconclusive, is still high in the SRM.

Biopsies are not consistently performed during ablation therapy. When performed, the literature shows a similar rate of nondiagnostic biopsies as in the case of SRM. Biopsy immediately performed after ablation leads to the same diagnostic yield as before ablation as architectural structure is still recognizable.

Current percutaneous renal biopsy is recommended when there is a suspicion of nonprimary RCC, when an infectious cause is suspected, during ablation therapy, to decide on treatment of SRMs, for therapeutic purposes in metastatic RCC, and for documentation and follow-up purposes when a RCC is submitted to active surveillance.

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CHAPTER 111

Percutaneous Radiofrequency Ablation of Kidney Tumors

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Introduction

The increasing incidence of renal cell carcinoma in the USA and worldwide [1, 2] is attributed to the increasing use of sectional abdominal imaging. Approximately 48–66% of all renal masses that are diagnosed, and 40% of all excised tumors are small renal masses (SRMs) [3]. SRMs are defined as tumors of less than 4 cm on abdominal imaging, of which 70–80% are malignant and 20% are benign.

Although radical nephrectomy (RN) had been the "gold standard" for treatment of organ-confined disease for several decades, growing evidence favors nephron-sparing surgery (NSS). Partial nephrectomy (PN) has now become the treatment of choice for most SRMs [4]. The evolution in incidence, presentation, and diagnosis of renal masses has prompted innovative ways of treatment with the goal of preserving renal function and decreasing morbidity.

The morbidity and mortality associated with chronic renal insufficiency with respect to cardiac events, stroke, and death are well established [5, 6]. Huang *et al*. showed that the risk of stage 3 or higher chronic kidney disease (CKD) was 20% after NSS and 65% after RN [7]. The morbidity for NSS (open and laparoscopic) includes, but is *not* limited to, urine leak, postoperative hemorrhage, wound paresthesias, hernia, flank bulge, and pain, and can be quite troublesome. The demonstration of equivalent cancer control with NSS as compared to RN has prompted the development of less invasive thermoablative techniques [like radiofrequency ablation (RFA) and cryoablation] in order to reduce the complications of NSS [8].

This chapter will focus on the development, application, and role of percutaneous RFA.

History

Biologic excitable tissue (i.e. nerve, muscle) can be stimulated readily by electrical energy with a frequency under 1000 Hz (i.e. household current of 60 A) but not by frequencies of 10 kHz or greater [9]. This basic principle was used in surgery for more than a century; from Edwin Beer (1910) and transurethral resection of bladder tumor; Henry Bugbee (1913) and an electrode to treat bladder neck obstruction; Max Stern (1926) and resectotherm for the prostate; and William Bovie and Harvey Cushing (1928) and electrosurgery [10, 11]. These inventions paved the way to the use of varying energy forms in therapeutic management of disease. The use of radiofrequency (RF) energy, an alternating electrical current (AC) with a wavelength between 10 kHz and 900 MHz, dates back to the 1960s, when RF energy was used to destroy central nervous system tissues for pain relief [12, 13]. Two decades later, Nath *et al*. and others described the use of RFA in the treatment of cardiac dysrhythmias to ameliorate aberrant conduction pathways [14–18]. The use of RFA for oncologic purposes did not occur until animal experiments were reported in the late 1980s for the treatment of metastatic liver lesions[19]. Application of thermal energy by means of radiofrequency to destroy benign or malignant tissues was

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proved to be successful for osteoid osteomas (canine) and small primary and metastatic liver lesions (humans) [20–22].

In 1996, Zlotta *et al*. described the first application of RFA technology to renal tumors in a human models and *in vivo* [23]. In this preliminary experience involving bipolar RFA of freshly removed human kidneys in an *ex vivo* model, the kidneys were perfused *ex vivo* with normal saline at 37°C to mimic the physiologic environment. Observations made from this study revealed that large reproducible controlled lesions were present in the renal parenchyma between the ablative needles [23]. One of the oversights in utilizing this model was the effect of perfusing the entire organ with an electrolyte solution, which allowed for the creation of very large lesions that could not be reproduced *in vivo*. Later, *in vivo* human RFA of renal tumors and subsequent resection confirmed most of the findings of the *ex vivo* model, prompting multiple other investigators to further explore RFA technology in the management of renal tumors in animal models and human. Walther *et al.* described the experience with four patients who underwent RFA treatment of 14 tumors just before surgical removal of the tumors [24]. Computed tomography (CT) was obtained prior and after ablation with no toxicity reported after the procedure.

The feasibility and safety of RFA as described above paved the way for the first application of the technique with the intent to treat renal cell carcinoma [25]. In this case report of an 84-year-old man who refused open surgical excision of a solid renal mass, CT demonstrated enhancement consistent with RCC that continued to enlarge over a 3-year interval to 3.5 cm. The patient consented to percutaneous RFA. Under conscious sedation the patient underwent percutaneous renal biopsy confirming RCC. A 17G internally cooled RFA needle electrode was used under realtime ultrasound guidance into the center of the tumor. The tumor was heated to 90°C for 1 min, followed by deposition of 1200 mA of current for 12 min. The patient tolerated the procedure well; 2-h, 1- and 3-month follow-up CT showed a nonenhancing lesion. McGovern *et al.* concluded that "successful percutaneous ablation may prove to be reasonable treatment alternative in patients who are at significant operative risk or when renal preservation is desired, such as those in whom von-Hippel–Lindau disease or other conditions predispose to multiple bilateral renal tumors" [25]. This statement proved to be the beginning of an indication to use RFA as a treatment method for RCC.

Fundamental concepts of radiofrequency ablation

Heat therapies convert radiant energy to thermal energy in tissues to achieve the goal of tissue destruction. This thermal energy is conducted primarily from cell to cell via diffusion in order to achieve cell death. Cell death or *ablation* is the consequence of several cellular changes, which are dependent on time and temperature (Figure 111.1).

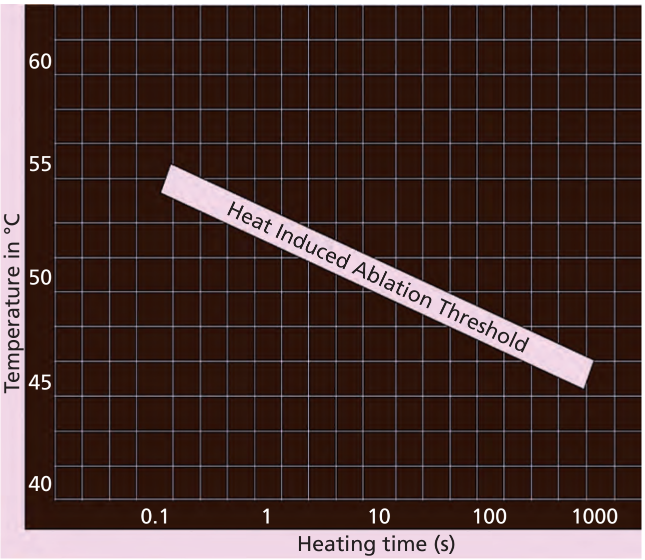

Figure 111.1 Relationship between temperature and time for thermal necrosis.

High temperatures causes one of the following:

- Immediate cell death by disruption of cellular architecture;
- Vaporization;
- Carbonization;
- Damage to essential cellular components (i.e. DNA, RNA).

At low temperatures (e.g. 45°C) it takes hours to promote *irreversible damage to cells*; at higher temperature (e.g. 100°C) it may take milliseconds to effect irreversible damage to cells and eventual cell death [9]. High temperatures cause immediate observable changes such as gross structural damage and vaporization or carbonization. Lower temperatures may result in deactivation of cellular enzymes involved in various functions; however, the cell's structural integrity (microscopic architecture) is maintained. Within hours, it is observed that the injury will lead to cell death via oncosis, followed by cellular and organelle swelling, and blebbing. Swelling eventually results in ischemia with appropriate cellular response leading to toxic levels of calcium within the cell, causing increased intracellular acidosis, which leads to denaturing of proteins, and eventually *coagulation necrosis*.

Coagulation necrosis is characteristic of cell death via hypoxia and ablation. In general, necrotic cells show increased eosinophilia attributable in part to loss of

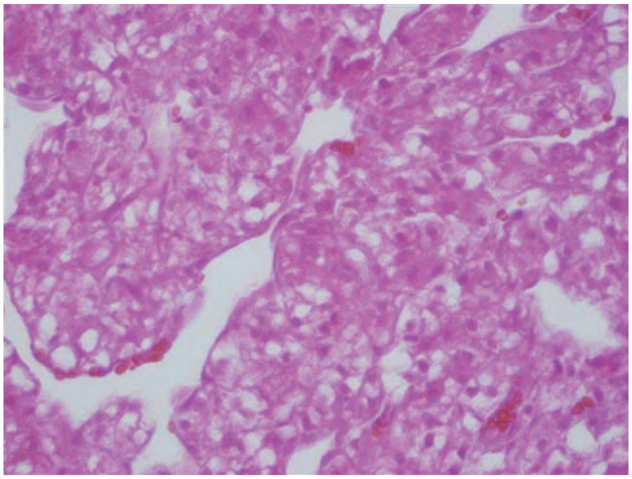

Figure 111.2 Postablation biopsy showing increased binding of eosin to denatured intracystoplasmic proteins. 60 × H&E.

the normal basophilia imparted by the RNA in the cytoplasm and in part to the increased binding of eosin to denatured intracystoplasmic proteins (Figure 111.2) The necrotic cell may have a more glassy homogenous appearance than that of normal cells, mainly as a result of the loss of glycogen particles. When enzymes have digested the cytoplasmic organelles, the cytoplasm becomes vacuolated and appears moth-eaten. Finally, calcification of the dead cells may occur. Dead cells may ultimately be replaced by large whorled phospholipid masses called myelin figures. These phospholipid precipitates are then either phagocytosed by other cells or further degraded into fatty acids; calcification of such fatty acid residues results in the generation of calcium soaps. Denatured proteins are observed under electron microscopy. Nuclear changes appear in the form karyokysis (fading of basophilia of the chromatin), pyknosis (nuclear shrinkage and increased basophilia, seen in apoptosis), and karyorrhexis (nuclear fragmentation) [26–29].

It is important to note that the morphologic appearance of coagulative necrosis is the result primarily of denaturation of intracellular proteins, and enzymatic digestion of the cell. The enzymes derive from the dead cells themselves, in which case the enzymatic digestion is referred to as *autolysis*; or from the lysosomes from migrating leukocytes, during inflammatory reactions. These processes require hours to develop and so there will be no detectable changes in cells immediately and 30 days after ablation [30, 31].

In addition, the temperatures created by RFA affect cellular metabolism and electrophysiology. The procedure causes microvascular and arteriolar occlusion, leading to ischemic changes in target tissues. This produces a predictable zone of coagulative necrosis that surrounds the ablative probe [30, 32].

Radiofrequency ablation

As discussed earlier, RFA involves the delivery of alternating current via monopolar or bipolar electrode to a target tissue with the intent to cause cell death. Radiofrequency energy can be introduced with a needle into tissue directly (dry RFA) or indirectly via ionic solutions (wet RFA) [33, 34]. The thermal tissue damage at high-temperature exposure can be predicted by means of the biophysical relationship in the Pennes Bioheat equation [35, 36].

The principles have been demonstrated in numerous *in vivo* studies: within defined temperature ranges, the thermal damage in tissue is approximately linearly dependent upon treatment time and exponentially dependent upon the increase in temperature. Accordingly, the Arrhenius analysis illustrates the variable sensitivity to heat exposure among different tissue types [37, 38]. The alternating electrical current is used to create resistive heating within the targeted tissue.

RF generators produce frequencies between 375 and 480 kHz, and power up to 250 W. The electrical energy is deposited in the tissue by means of a probe with a diameter of 1.6–2.5 mm insulated up to 2–5 cm in length [35]. In conventional "dry" monopolar RFA systems, the electrical circuit is established between the active applicator tip and one or several grounding pads, usually attached to the patient's thighs. The thermal heating is more intense close to the active needle tip, because of the narrow electrical streamlines, and has the highest current density. The highest tissue temperatures are reached at only a few millimeters surrounding the applicator tip, and via convective heating the resulting coagulative necrosis takes effect. In "dry" or conventional RFA, charring and tissue boiling close to the active needle tip increases impedance and therefore limits the zone of ablation. Goldberg *et al*. presented strategies to further increase induced coagulation necrosis, describing using multiprobe and bipolar arrays, and internally cooled radiofrequency electrodes, with or without pulsed-radiofrequency or cluster technique, and use of wet electrodes [36–38]. The development of these strategies allows for further increase of the coagulation diameter, while decreasing impedance.

Further increase of the coagulation diameter via augmenting the distance between the needles in the multiapplicator approach is not possible due to electrical shadowing in the center of the applicators [35]. Several overlapping ablations with intermittent repositioning of the applicator are performed for tumors greater than 3 cm. Pereira *et al.* directly compared the efficacy of perfusion, cooled-tip, nine- and 12-tine cluster electrodes in pig livers [39]. This group found that larger coagulation volumes were indeed created with the perfusion and cooled-tip electrodes. The multiple-tine devices created a more spherical lesion and were found to have better reproducibility. Bipolar and multipolar devices are now available [40], and used to achieve larger coagulation diameters and better-controlled energy deposition. Studies using some of these techniques have demonstrated ablation diameters of up to 7 cm with the placement of three applicators in a triangular fashion [41, 42]. With discovery and modifications in current technologies, the application of these principles continues to improve the efficacy and safety of RFA.

Radiofrequency ablation of renal tissue: experimental and histologic consideration

As described in the history of RFA above, thermal energy for target tissue destruction has been applied to the brain, bones, heart, lung, kidney, prostate, spleen, and liver. Several investigators have performed RFA for kidney in animal models and human studies [30–33, 43–47].

A number of investigators have undertaken the pathologic and histologic examination of the renal coagulation induced by RFA [30–33, 47–51]. Gross examination has revealed coagulation necrosis, which appears as a well-circumscribed blanched and yellowish–tan colored tissue. The histologic appearance on light microscopy reveals blurred nuclear chromatin, an increase in eosinophilia, loss of cell integrity, and presence of hemorrhage. Electron microscopy reveals prominent cytoplasmic granularity and near total loss of ultrastructural detail of the cytoplasmic organelles [35]. Within 2–4 weeks, the loss of cellular integrity occurs, as evidenced by nuclei lyses, cell membrane degeneration, and cellular fragmentation, and leads to coagulative necrosis in the ablated area. Tissue edema, inflammatory cells, neovascularization, and interstitial hemorrhage mark the inflammatory response around the coagulated area [30]. Microscopic and gross observations reveal distinct demarcation between the ablated renal tissue and the surrounding renal parenchyma. Investigators are able to distinguish four *zones of ablation* from the center to the periphery of the ablated renal lesion [48, 49]:

- Zone 1: carbonization occurs in the area of the renal lesion in direct proximity to the RFA probe;
- Zone 2: area of complete necrosis;
- Zone 3: area containing inflammatory cells and hemorrhage;
- Zone 4: normal renal parenchyma.

It is important to note that the tissue carbonization caused by the high temperatures used in RFA acts as a barrier to ablation (impedance), which investigators continue to work to overcome.

Over a few weeks to months, the ablated lesion shrinks due to absorption and fibrotic conversion of the coagulated lesion [32]. The histologic examination of the ablated lesion remains a subject of controversy. Corwin *et al*. evaluated the effectiveness of RFA in a porcine model using hilar occlusion techniques, and showed using nicotinamide adenine dinucleotide (NADH) staining that there were nonviable tissues after RFA. Marcovich *et al.* investigated and compared the histologic characteristics of RF-ablated porcine renal tissue using NADH and H&E staining [49]. The kidneys were immediately harvested, gross lesion size was measured, and tissue was processed for standard H&E and NADH staining. H&E staining of ablated tissue revealed a number of alterations in renal tubular histology. However, all of these findings were focal, with areas of parenchyma that appeared well preserved. Corresponding areas on NADH-processed sections showed the complete absence of staining, indicating the lack of cellular viability. There were no skip areas noted on NADH-processed sections and treated portions demonstrated a well-demarcated border of ablation. The authors concluded that while RFA produces discernible histologic changes acutely on H&E, these alterations are variable and patchy, and they alternate with areas of well-preserved tissue. In a recent study by Queiroz *et al*. to determine the efficient temperature for RFA of renal cells in a dog model, the authors indicated that H&E microscopic staining is optimal 14 days after RFA [50, 51]. Therefore, to assess and verify cellular death in RFA lesions, some authors recommend that NADH staining should be used [48], although this is not widely utilized because postablation biopsy is not routine.

Percutaneous radiofrequency ablation

McGovern *et al.* were the first to report the use of ultrasound guidance for RFA of renal tumors with the intent to treat [25]. The use of RFA as a treatment modality for renal tumors from its inception in 1999 to the present has paralleled the increased utility of NSS for indicated tumors; the main aim is to destroy the same volume of tissue that is usually removed with partial nephrectomy.

Bandi *et al*. determined the general trend in current practice of use of ablative technology for the management of SRMs at academic centers in the USA. An email survey was sent to 112 academic urologists subspecializing in minimally invasive ablative technology. Among the 62% of respondents, 93% of academic urology centers used ablative technology, offering either cryoablation (79%) and/or RFA (55%) [52].

Indications

There is no randomized controlled trial comparing partial nephrectomy and RFA for the treatment of small renal masses. Most reports on percutaneous RFA are based on single-center retrospective studies. These studies indicate that RFA is an effective and safe treatment option for renal tumors in appropriately selected patients [44]. The use of percutaneous RFA as a strategy for treatment of SRMs has to be defined in the context of the overall clinical situation, including age and life-expectancy, radiologic assessment of local and distant disease burden, and patient compliance.

The indications for percutaneous RFA are similar to those for NSS [53], i.e. a contrast-enhancing SRM, T1a (<4 cm) or T1b (4–7 cm) (Table 111.1). Percutaneous RFA is effective generally in patients who have an absolute indication for NSS: synchronous bilateral renal masses, tumors in a solitary kidney, and presence of a poorly functioning contralateral renal unit. Percutaneous RFA is particularly effective and safe for patients harboring an SRM, with normal contralateral renal unit, and who are poor candidates for extirpative surgery.

The increased diagnosis of incidental renal masses in elderly patients with multiple medical comorbidities, including chronic renal insufficiency, requires a maximally nephron-conserving approach to management. Because up to 25% of SRMs are benign lesions with low metastatic potential [54–56], a conservative approach in the form of active surveillance or RFA has emerged for elderly patients who prefer proactive intervention.

Other indications for percutaneous RFA include RCC associated with familial renal cell carcinoma syndromes, i.e. von Hippel–Lindau (VHL) syndrome and hereditary papillary RCC presenting as multifocal lesions for which multiple partial nephrectomies might be cumbersome or impossible. Percutaneous RFA in patients with advanced or metastatic disease is primarily indicated to avoid rendering the patient anephric [57] and necessitating renal replacement therapy or dialysis. With primary tumor ablation, symptomatic relief may be possible while maintaining acceptable renal function. Overall survival has not been demonstrated for this indication in NSS or RFA; however, with the combination of radical nephrectomy and chemotherapy a slight increase in life-expectancy has been described [58]. Some authors suggest that complete ablation of renal tumors plus drug therapy may be a feasible option for carefully chosen candidates.

It is important to note that location and size of a renal tumor does not preclude the utility of percutaneous RFA. However, tumor size and location are strong predictors of ablation outcome in percutaneous RFA. With tumors less than 3 cm, complete ablation is achieved in most cases with one single session. In tumors greater than 5 cm repeated cycles may be required during a percutaneous RFA treatment to achieve the desired ablation outcome [59]. This applies for centrally located tumors that carry much lower ablation rates because of their proximity to the renal hilum, due to cooling effect of central blood vessels, the “heat sink” phenomenon [60]. The utility of percutaneous RFA is contingent on appropriate informed consent by patients willing to undertake this approach for tumor management.

Table 111.1 Indications for radiofrequency ablation.

Bilateral renal tumors
Multiple tumors in patients with VHL
Solitary kidneys will small renal mass (SRM)
Patients having SRM and renal impairment
Patients with SRM and not considered “fit for surgery”
Patient choice: SRM, when patient does not want surgery
Post partial nephrectomy local recurrence

Contraindications

Percutaneous RFA is best suited for posterior or laterally located tumors, but the presence of intestine or ureter within 1 cm of the ablation zone is a contraindication to this approach because thermal injury to these structures can occur (Table 111.2). Further contraindications include blockage of probe placement by intervening liver, spleen or lung. Problems may arise in tumors exhibiting large cystic components, as percutaneous RFA is less effective for cystic lesion. Finally, location immediately adjacent to the body wall or diaphragm is a relative contradiction because thermal injury to the musculature and nervous structures can lead to increased postoperative pain. Laparoscopic RFA is best

Table 111.2 Contraindications to radiofrequency ablation.

Absolute contraindications
Uncontrolled bleeding diathesis

Relative contraindications
- Patients on anticoagulation: needs correction before procedure
- Confounding anatomic factors:
  Pleura open up after positioning
  Proximity of bowel, ureter or adrenal gland
  Cystic tumors
  Obvious proximity to large vessels
- Technology: absence of good imaging/multislice CT
- Surgeon factors: inexperienced operator

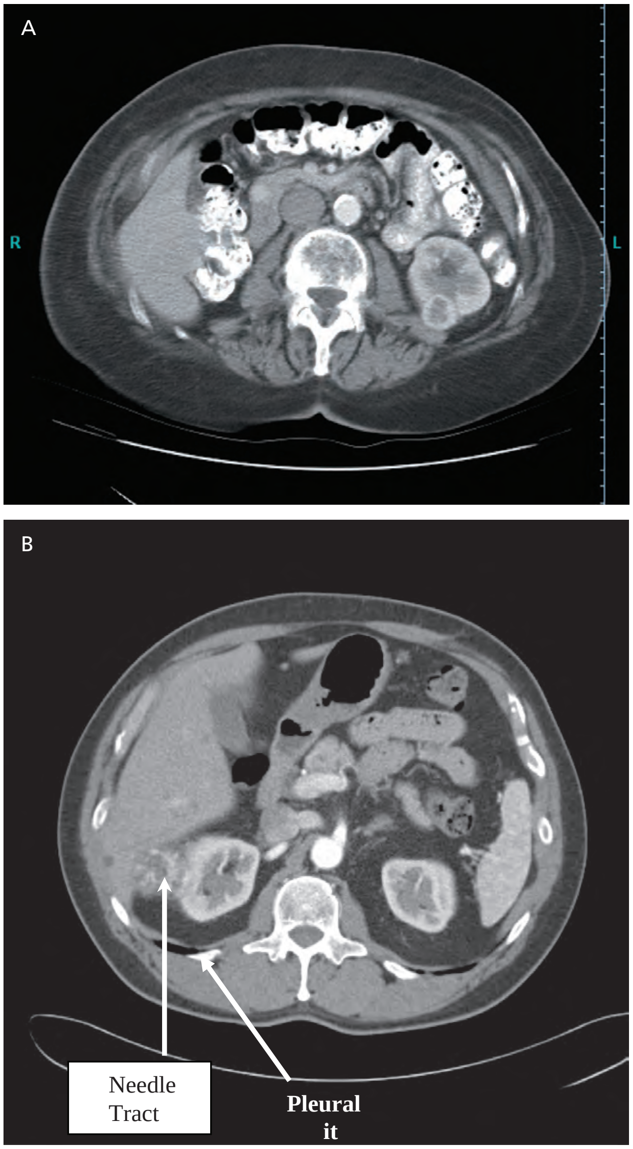

Figure 111.3 Preoperative evaluation. (A) Preablation contrast-enhanced CT scan showing a posterior solid enhancing renal mass. This location is ideal for CT-guided radiofrequency ablation. (B) Inferior extent of pleural cavity visible at mid portion of right-sided tumor. Extra caution must be used to avoid transpleural puncture. Options include oblique needle placement or transhepatic percutaneous placement. Laparoscopic exposure would also be a safe alternative.

Table 111.3 Comparison of ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI) modalities in radiofrequency ablation (adapted from Leveillee and Ramanathan [61]).

	Ultrasound	CT	MRI
Pretreatment assessment	Good	Excellent	Excellent
Probe placement	Good	Excellent	Excellent
Temperature monitoring	Not possible	CT thermography possible	MR thermometry possible
Monitoring of ablation	Imaging deterioration occurs	Possible	Possible
Needle relocation	Technically difficult due to image deterioration	Possible	Possible
Realtime imaging	Possible	Difficult	Difficult
Radiation exposure	No	Yes	No

Table 111.4 Four-stage process to be completed prior to radiofrequency ablation.

Stage 1	*Preoperative assessment* Preoperative imaging and treatment planning
Stage 2	*Intraoperative assessment* Imaging, planning, and targeting
Stage 3	*Perioperative monitoring* Temperature probes, thermography, and assessment of complete ablation
Stage 4	*Postoperative follow-up* Assessment of completeness of ablation and detection of recurrence/metastases/new metachronous tumors

suited for anterior or medially located tumors as this allows for laparoscopic mobilization of the bowel, exposure of the tumor surface, and direct visualization of insertion of the ablation probe into the tumor parenchyma for efficacy and safety. Laparoscopic exposure reduces the risk of thermal injury to adjacent organs. In addition to intestinal mobilization and protection, laparoscopic approaches allow separation of other vital structures, including the ureter and renal pelvis from the ablation zone. We have not experienced thermal damage to the ureter, renal pelvis, vasculature, or bowel when diligent dissection and mobilization was performed (Figure 111.3).

Technique and modalities

Percutaneous RFA can be performed with one the following methods of image guidance: CT, magnetic resonance imaging (MRI) or ultrasound (Table 111.3).

A four-stage process should be initiated prior to RFA to ensure successful treatment at the time of ablation [61] (Table 111.4). Prior to intervention, a thorough

Table 111.5 Radiofrequency ablation devices.

LeVeen System	RITA system	Cool Tip™ system
Gradual increase in power in response to changes in tissue impedance Impedance based	Consists of several thermistors at the tip of a multitined dry needle with the goal of reaching maximum temperature Temperature based	Based on combination of both tissue impedance with tissue cooling and endpoint of maximal temperature

history and physical examination of the patient is completed. A CT renal mass protocol is used to delineate the renal tumor prior to ablation. MRI with gadolinium enhancement is an alternative for patients with renal insufficiency [glomerular filtration rate (GFR) > 30 mL/min/1.73 m^2). Laboratory values are obtained, including a coagulation panel, and a well-written informed consent to treatment is obtained from the patient.

A CT renal mass protocol is used to delineate the renal tumor prior to ablation. MRI with gadolinium enhancement is an alternative for patients with renal insufficiency who have a GFR greater than 30 mL/min/1.73 m^2). After the team has reviewed the preoperative imaging, the probe type, location, and circuit type are determined based on tumor characteristics, size, and anatomic relation to other structures. A collaborative and coordinated effort between the urologist, interventional radiologist, anesthesiologist, surgical nurse, and technician is essential to successful treatment of the patient [61].

Prior to the procedure, the urologist and, or interventional radiologist must decide on the type of RFA device used. In the USA, there are three monopolar systems capable of delivering up to 250 W of power (Table 111.5):

- Cool Tip™ RF system (Covidien, Boulder, CO, USA);
- LeVeen RF system (Boston Scientific, Natick, MA, USA);
- RITA RF system (Angiodynamics, Queensbury, NY, USA).

The different RFA devices involve either temperature or impedance feedback loops, in which the generators modulate the amount of electrical current delivered to the probe. The heating of renal lesions varies with the amount of current delivered to the lesion; too much electrical energy delivered to the tissue causes charring around the electrode, therefore impeding complete tumor ablation. To prevent this problem, RF generators control the amount of power delivered to the probe based on either temperature or impedance feedback from the probe and manufacturers' algorithms [62].

RF probes are either single- or multi-tined probes and cooled tip probes. The use of multiple tines has the theoretical advantage of spreading electrical current over a larger area, creating a larger zone of ablation without charring around the probe. The Cool Tip™ electrode (Covidien) is a single-prong electrode that circulates saline or other liquid coolant within the electrode to decrease the temperature of the probe and the immediate surrounding tissue. This prevents charring around the probe and allows more energy to be delivered into the tumor.

Percutaneous RFA is carried out under general anesthesia or conscious sedation. Some investigators (including us) advocate the use the use of general anesthesia when possible, which is thought to optimize patient tolerance; allow for greater respiratory control during probe placement, improving targeting to tumor; and potentially give a better outcome [63]. Intravenous sedation offers the advantage of decreased morbidity from general anesthesia and the ability to perform RFA as an outpatient only procedure. Gupta *et al*. presented outcomes of percutaneous RFA of 163 renal tumors in 151 patients who underwent general anesthesia prior to ablation [63]. Comparison of their series with other series using intravenous sedation showed initial complete ablation rates were higher in the general anesthesia series than in the conscious sedation series. However, the authors caution the interpretation of these findings given the heterogeneity in eligibility criteria, variation in technique, definition of incomplete ablation, methodology of data analysis, and presentation of results. As such, there is insufficient evidence in the literature to advocate use of one method of anesthesia over another.

Probe placement of RF needles is accomplished under ultrasound, CT, or MRI guidance. In published data, most authors prefer CT guidance, which is used in over 70% of percutaneous RFAs performed in the USA [52]. Some high-volume centers perform percutaneous RFA efficiently with excellent results using conscious sedation and other forms of image guidance [52, 59, 64–71].

Image guidance with CT is performed with or without intravenous contrast. The use of intravenous contrast helps to accurately image the lesion in question. Accurate identification of the tumor and other structures (spleen, liver, bowel, lung, and surrounding pleura) is essential in planning percutaneous access to the lesion. Several methods of bowel manipulation have been described and continue to be refined to increase the separation between vital structures and the renal lesion.

The patient is placed in a prone or full flank position (Figures 111.4 and 111.5) to provide percutaneous access to the retroperitoneum. If peripheral temperature monitoring is performed, two to three fiberoptic temperature sensors (LumaSense, Santa Clara, CA, USA) are placed

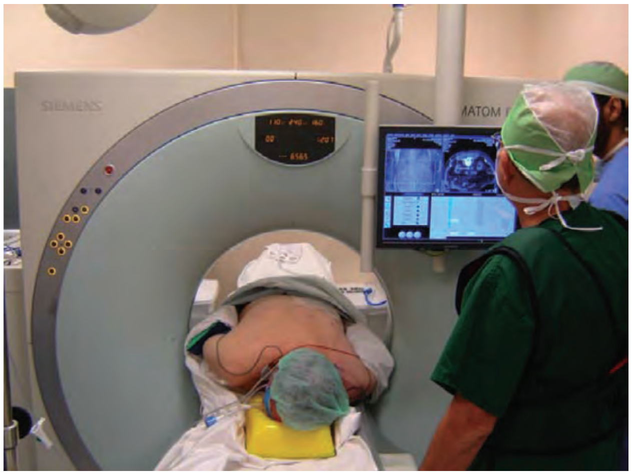

Figure 111.4 Patient positioning for CT-guided radiofrequency ablation.

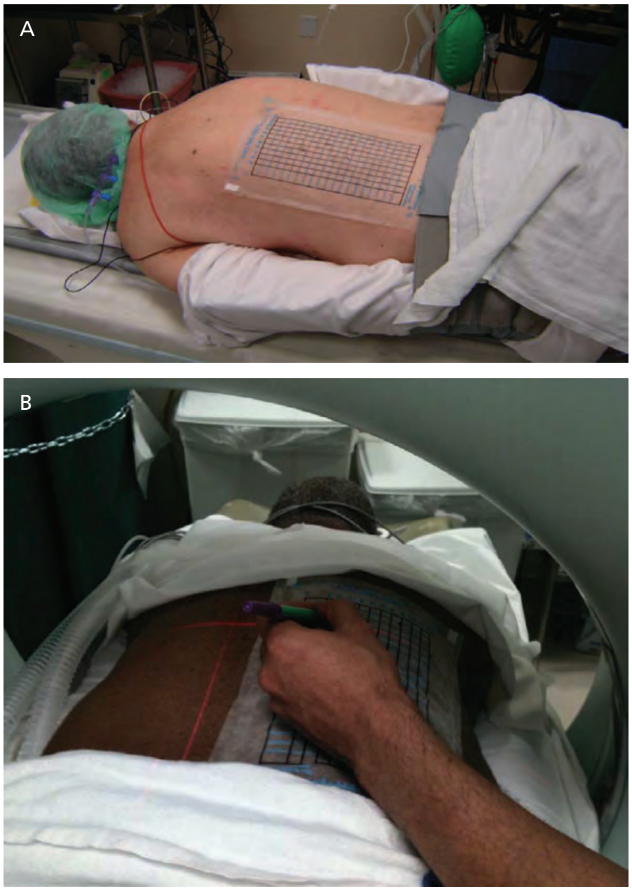

Figure 111.5 Localization grid with patient in prone position (A) outside and (B) under the CT scanner.

under CT guidance (or other choice of imaging modality) at the peripheral (superior, inferior, lateral, and medial) and deep margins of the tumor, 5 mm from the tumor–parenchyma interface (Figures 111.6–111.9).

Nonconducting 18G sheaths are placed (TLA or Yueh) and the probes are then inserted via the sheaths. Prior to ablation, biopsies of the tumor are obtained with a spring-loaded (i.e. Tru-Cut) biopsy needle to obtain a diagnosis (see Chapter 110). A frozen section may or may not be requested (we do not).

It is not routine to use intravenous contrast during CT-guided ablation if preoperative imaging is done with contrast and demonstrates a well-defined tumor border. Injection of contrast can only be performed once per ablation session because it requires several hours for clearance.

The probes are positioned under CT guidance percutaneously, directed toward the center of the tumor, and advanced until the deep margin is reached with the probe tip (Figures 111.7 and 111.8). If expandable ablation needles are used, these are deployed according to the manufacturer's algorithm. Positioning of the ablation needle is performed and RFA is initiated. Complete ablation is achieved at a specific time interval, at which point a "target temperature" or impedance is reached at the probe tip or the peripheral temperature monitors, i.e. when all "target temperatures" have been achieved at the tumor margins (>5 mm, 60°C). To achieve the optimal temperature, manipulation and alternate targeting of the RF probes and repeat application of radiofrequency energy is necessary [72] (see Video 111.1).

MRI-guided RFA has been used by various authors as the imaging modality of choice [73–75]. The delivery of radiofrequency energy is performed using custom-manufactured MRI-compatible "cooled-tip" radiofrequency probes using a temperature-controlled system. According to Lewin *et al.*, single or multiple ablation cycles of 12–15 min at 90°C are applied until the entire tumor is replaced by a zone with low signal intensity on T2-weighted and/or short inversion time inversion-recovery images [73]. This allows for "realtime" monitoring of ablation. MRI on T2-weighted images demonstrates clear postablation changes that appear to be reproducible [76]. In the acute phase after ablation, the hypointense area of complete necrosis is typically surrounded by a small hyperintense rim, which corresponds to the zone of inflammation and hemorrhage. Residual tumor tissue can be detected due to its persisting isointense or hyperintense signal. The area(s) of incomplete treatment is further ablated with repositioning of the probe. Subsequent RFA can be performed multiple times during the same session, which allows for repeated assessment of ablation outcome using MRI without injection of contrast. This provides an added advantage over all the other imaging modalities. The success rates of complete tumor ablation are comparable to CT-guided ablation at 92–100% of cases within one single session [72].

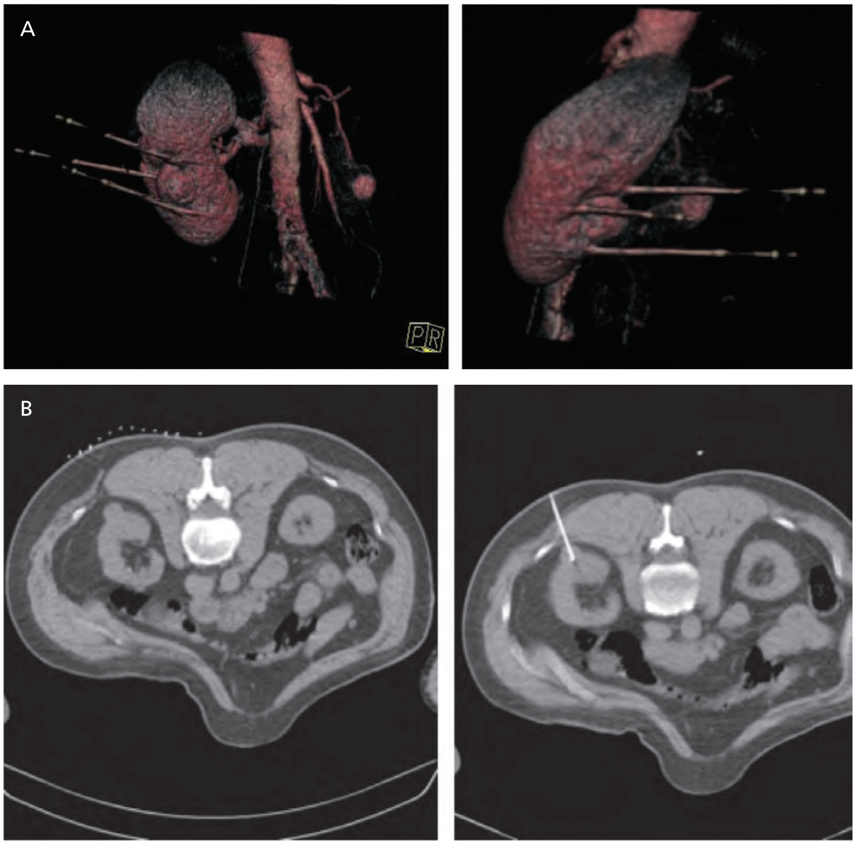

Figure 111.6 (A) Three-dimensional reconstruction of peripheral temperature monitoring guide needles. (B) Ablation needle placement through right posterior tumor center (prone position).

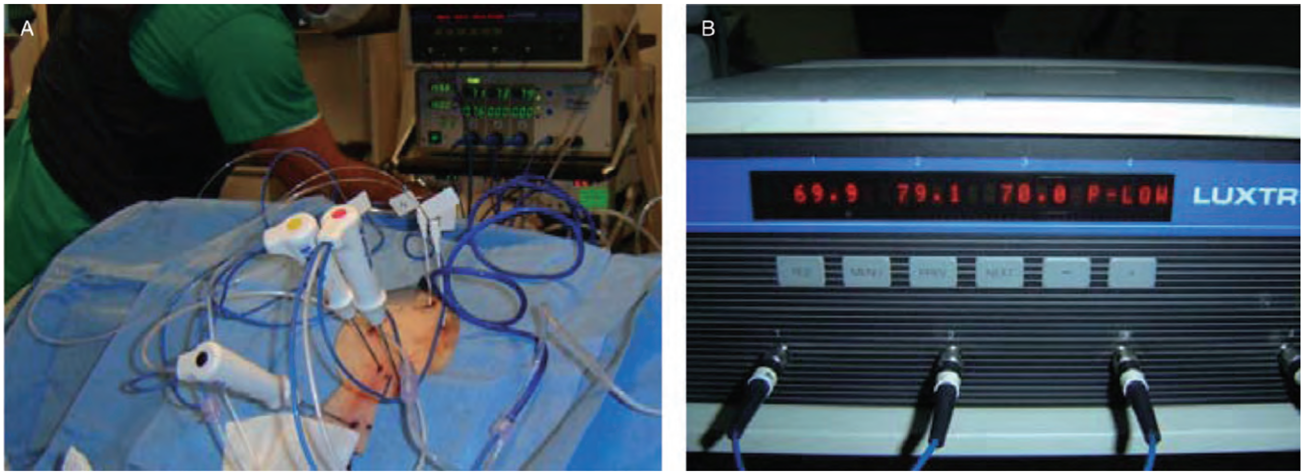

Figure 111.7 Realtime temperature monitoring performed through fiberoptic monitors; ablation is complete when all temperatures exceed 60°C.

Ultrasound-guided ablation is the least used modality in the treatment of renal lesions with radiofrequency energy. The production of gas bubbles by vaporization during the procedure significantly disturbs image quality due to hyperechogeneity [35]. While investigators continue to explore ways to improve ultrasound-guided RFA [40], in light of inherent limitations of CT and MRI guidance [77], its use remains limited and requires further evaluation.

Outcomes/results

The use of ablative therapy for SRM management is accepted as primary treatment for patients with comorbidities who are poor candidates for surgical resection. The promising outcomes from various centers have led many investigators, including us, to encourage the use of needle ablative therapy in healthy, younger patients. Local eradication of the tumor is the primary aim of treatment. There is significant controversy regarding the definition of success. The Working Group on Image-Guided Tumor Ablation defined successful ablation as completely treated renal mass with no residual tumor left behind [78–80]. The American Urological Association when drafting its guidelines for the treatment of SRM used a very strict definition, "For the ablation studies, local recurrence was defined as any localized disease remaining in the treated kidney at any point after the first ablation treatment."

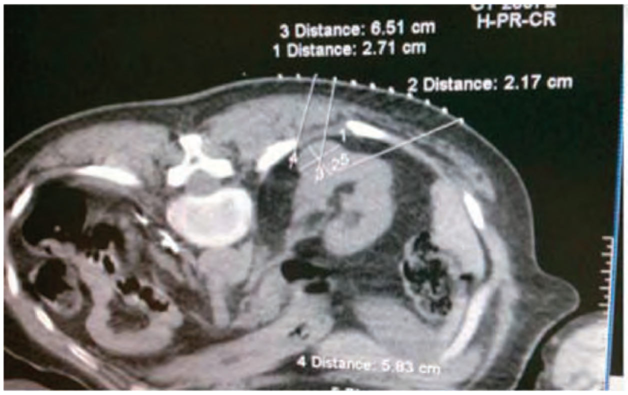

Figure 111.8 Planning with markers and targeting depicted on a noncontrast CT scan.

The initial success of percutaneous RFA in the treatment of RCC has led to its increased use in patients who opt to undergo minimally invasive treatment. With well-defined, short-term efficacy, intermediate and long-term cancer control rates for this emerging technology are becoming more available and the results continue to be very encouraging (Table 111.6).

Levinson *et al*. reviewed the overall oncologic and survival outcomes in patients with a solitary renal mass treated using RFA at follow-up of at least 40 months [81]. Patients were offered RFA due to the high risk of surgical management and surgeon preference. Follow-up consisted of serum creatinine measurement, physical examination, and serial contrast-enhanced CT or MRI. The 31 patients received a total of 34 RFA treatments to a 1.0–4.0-cm solitary renal mass (median 2.0 cm). Mean follow-up in survivors was 61.6 months (median 62.4 months, range 41–80 months). There was one primary treatment failure, which was successfully retreated, and three recurrences at 7, 13, and 31 months after RFA, respectively. The overall recurrence-free survival rate

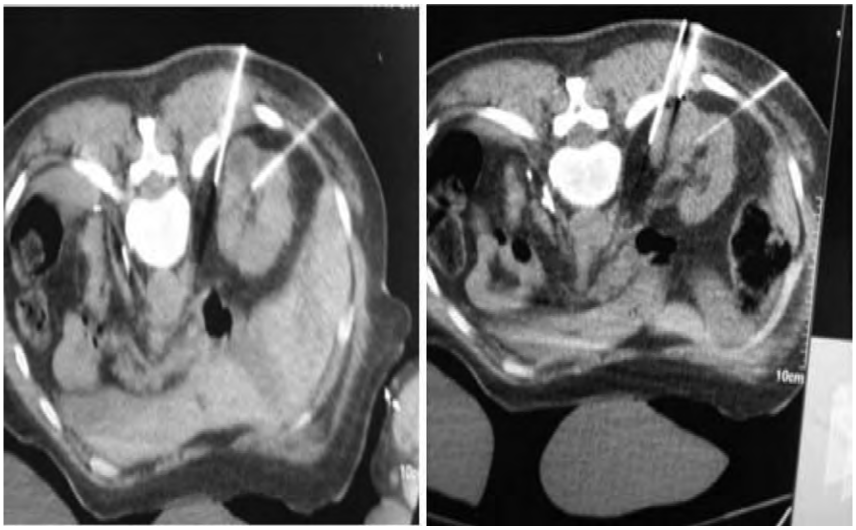

Figure 111.9 Temperature sensor placed in the periphery of the tumor and ablation probe in the center of the tumor.

Table 111.6 Results for percutaneous radiofrequency ablation.

Study	Success rate %	Modality	Follow-up (months)
Farrell *et al.* (2003) [100]	100	US	1–23
Mayo-Smith *et al.* (2003) [70]	87	US/CT	1–36
Gervais *et al.* (2005) [67]	91	US/CT	3.5–72
Ahrar *et al.* (2005) [86]	96	CT	1–33
Weizer *et al.* (2005) [101]	92	CT	1–28
Arzola *et al.* (2006) [91]	90	CT	7–53
Veltri *et al.* (2006) [102]	89	US	1–54
Breen *et al.* (2007) [66]	90	US/CT	1–76
Zagoria *et al.* (2007) [65]	93	CT	1–76
Rouvière *et al.* (2008) [103]	95	US/CT	3–84
Levinson *et al.* (2008) [81]	90	CT	41–80
del Cura et al (2010) [40]	91	US	10–50
Carey *et al.* (2007) [89]	100	CT	1–12
Salagierski *et al.* (2010) [104]	90	US	0–60
Gupta *et al.* (2009) [63]	97	CT	1–70
Park *et al.* (2009) [99]	100/72	CT and US	N/A
Boss *et al.* (2005) [74]	100	MRI	N/A

was 90.3%. There was a 100% metastasis-free and disease-specific survival rate in the cohort. Overall patient survival was 71.0% since nine died of non-RCC causes. Of the 31 patients, 18 had pathologically-confirmed RCC. In these 18 cases, the actuarial disease-specific, metastasis-free, recurrence-free and overall survival rates were 100%, 100%, 79.9%, and 58.3%, respectively, at a mean of 57.4 months of follow-up. In the entire cohort the difference between the pretreatment and the last known serum creatinine level was 0.15 mg/dL ($P = .06$). The authors concluded that in patients who have limited life-expectancy or are high-risk surgical candidates, RFA provides reasonable long-term oncologic control and it may have a role in the management of SRMs.

Tracy *et al.* presented one of the largest series to date evaluating the long-term oncologic outcome after RF ablation for small renal tumors [82]. The authors report their experience with RFA of SRMs in the management of 208 patients (with 243 tumors) over the past 7.5 years, with particular attention to 66 patients (with 84 tumors) who had a documented radiographic follow-up of at least 3 years. The initial treatment success rate was 97%, and the overall 5-year recurrence-free survival rate was 93% (90% for 160 patients who had biopsy-proven RCC). During follow-up, three patients developed metastatic disease, and one died of RCC, yielding 5-year actuarial metastasis-free and cancer-specific survival rates of 95% and 99%, respectively.

In addition to strengthening the current intermediate-term evidence of RFA efficacy, these results appear to compare favorably with those for cryoablation of SRMs. In the longest detailed follow-up study available for cryoablation, Aron *et al*. reported 5-year overall, disease-specific ,and disease-free survival rates of 84%, 92%, and 81%, and 10-year rates of 51%, 83%, and 78%, respectively [83]. These data are comparable to the most recently published reports on RFA, with rates of 93%, 99%, and 85%, respectively for 5-year follow-up [82]. It is important to note that in the RFA series, 71% of the tumors were treated percutaneously, while the approach in 100% of the cryoablation series was laparoscopic.

The radiofrequency technology was embraced by interventional radiologists, whereas cryoablation delivered laparoscopically seems to have been accepted early by surgeons, despite minimal evidence to support its superiority. The major attraction in favor of freezing techniques has long been the visualization of the targeted "ice ball" and reduction in tumor diameter in follow-up imaging. It must be remembered, however, that these two ablative techniques manifest their effect through entirely different mechanisms and cannot be easily compared head-to-head. Another important point of distinction is the *intent-to-treat* in earlier series by interventional radiologist or urologists, which during initial experience led to repeat ablations. The results when later interpreted showed a "perceived" increased recurrence compared to cryoablation.

Renal functional outcome

RFA is advocated in patients with multiple comorbidities who are poor surgical candidates. Inherent in these patients is a baseline renal insufficiency, all of whom have some degree of CKD. RFA gives the opportunity to obviate the need for hilar clamping and ischemia, and is an alternative for patients with baseline renal dysfunction. Numerous investigators have sought to define the renal functional outcome in patients undergoing definitive RFA of renal tumors [81, 84–91].

Using the Modification of Diet and Renal Disease equation, Raman *et al.* calculated and compared the median GFR change in 47 patients with a solitary kidney after RFA to 42 patients undergoing open partial nephrectomy (OPN) [89]. The median age (65.9 vs 59.6 years, $P = .03$) and American Society of Anesthesiology score (3.0 vs 2.0, $P = .01$) were both higher in the patients treated with RFA. The median tumor size was greater for tumors managed by OPN (3.9 vs. 2.8 cm, $P = .001$), while the median preoperative was lower in the RFA group (46.5 vs 55.9 mL/min/1.73 m^2 for OPN, $P = .04$). Compared to RFA, patients treated with OPN had a greater decline in GFR at all times evaluated, including soon after the procedure (15.8% vs 7.1%), 12 months after surgery (24.5% vs 10.4%) and at the last follow-up (28.6% vs 11.4%, all $P < .001$). For patients with a pretreatment GFR of greater than 60 or less than 30 mL/min/1.73 m^2, there was a new onset of decline in GFR of less than 60 and less than 30 mL/min/1.73 m^2 in 0% and 7% of patients after RFA, and in 35% and 17% after OPN. The authors concluded that RFA may obviate ischemic insults, and is favorable option for managing tumors in solitary kidneys at risk of declining function [89].

In a landmark study, Lucas *et al*. evaluated renal functional outcome of 242 consecutive patients from July 1995 to March 2005 undergoing primary treatment for unilateral renal masses smaller than 4 cm and a normal contralateral kidney [92]. Renal function was calculated using the modified Modification of Diet in Renal Disease equation. The rate of decrease in the GFR below 60 mL/min/1.73 m^2 was compared among three treatment arms: 86, 85, and 71 patients were treated with RFA, partial nephrectomy, and radical nephrectomy, respectively. Preoperatively stage 3 CKD (GFR < 60 mL/min/1.73 m^2) was identified in 65 patients (26.7%), including 26.7%, 27.1%, and 26.8% of those who underwent RFA, partial nephrectomy, and radical nephrectomy, respectively. Following intervention, the 3-year freedom from a GFR decrease of below 60 mL/min/1.73 m^2 for RFA, partial nephrectomy, and radical nephrectomy was 95.2%, 70.7%, and 39.9%, respectively ($P < .001$). Multivariate analysis showed that radical nephrectomy was an independent risk factor versus RFA and partial nephrectomy for stage 3 CKD (HR 34.3, 95% CI 4.28–275 and 10.9, 95% CI 1.36–88.7, respectively). The authors concluded that decreased renal function is prevalent in patients with SRMs, even those with a normal contralateral kidney, and ablative or extirpative nephron-sparing techniques are effective for preserving renal function in these patients. These data suggest that RFA provides the lowest rate of renal impairment, which can be attributed to the lack of vascular clamping used in extirpative NSS.

Complications and strategies for their prevention

Complications described with RFA include hemorrhage requiring blood transfusion (2.3%) [59]; abscess formation mimicking tumor recurrence [93]; ureteral strictures, ureteropelvic junction obstruction, and delayed hemorrhage [94]; reno-colic fistula [95]; renoduodenal fistula [96]; and neuromuscular complications [97] with paresthesia in the distribution of the genitofemoral nerve when ablating lesions near the psoas muscle. Treatment of central tumors is most likely to cause hematuria, which is usually self-limiting [86].

Ablating the probe track during removal minimizes the likelihood of tumor seeding along it after biopsy or ablation [98].

Many of the above complications are related to proximity of the tumor to neighboring organs [99]. In order to avoid many of them, the distance between the tumor and neighboring organs may be increased artificially by using methods such as changing the patient's position, using the radiofrequency electrode as a lever, and hydrodissection [99] . A postablation CT is useful in identifying the presence of a pneumothorax or perirenal hematoma.

Follow-up after ablation

Patient follow-up should include adequate history, physical examination, chest X-ray, creatinine, and contrast-enhanced CT or MRI studies at specified intervals (see below). Our standardized follow-up protocol is given in Table 111.7.

Conclusions

Although long-term data are being accumulated, multiple and recent series continue to demonstrate near

Table 111.7 Follow-up protocol.

1–3 months	CT scan: renal mass protocol (Figure 111.10)
6 months	CT scan: renal mass protocol Chest X-ray
Annually thereafter × 4	CT scan: renal mass protocol Chest X-ray Liver function tests (LFTs)
Thereafter × 5	CT scan: renal mass protocol Annual Chest X-ray Annual LFTs

Dedicated chest CT with/without contrast if any suspicious lesions on chest X-ray or upper cuts of CT abdomen.
Bone scan/dedicated radiographs if suspected lesions.
Suspicious lesions may need to be biopsied (laparoscopic, VATS-guided or percutaneous image-guided).
Incomplete ablation is defined as persistent quantifiable contrast enhancement at any point greater than 1 month after initial ablation. Although the definition of recurrence remains controversial, we define recurrence as contrast enhancement after at least 6 months.

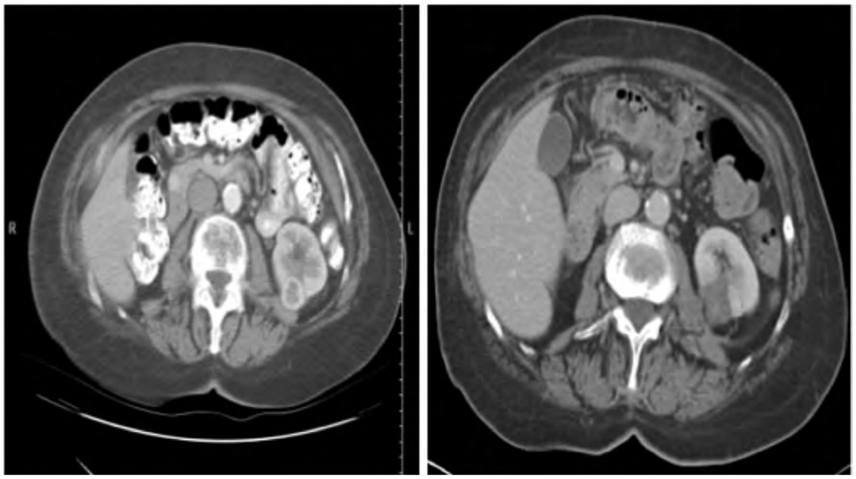

Figure 111.10 Post radiofrequency ablation surveillance CT scan at 1–3 month follow-up.

equivalent oncologic outcomes when RFA is compared to extirpative surgeries for SRMs. The added benefit of minimal invasiveness and renal function preservation continues to make RFA increasingly popular for definitive management of appropriately selected tumors and patients.

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CHAPTER 112

Percutaneous Cryoablation for Renal Tumors

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Introduction

In 2009 there were an estimated 57 670 new cases of kidney cancer in the USA alone [1]. The majority of these tumors are confined to the kidney and therefore amenable to curative treatments. Historically, radical nephrectomy had been the treatment of choice, demonstrating excellent oncologic efficacy. However, with the recognition of the long-term adverse affect of renal loss on patient comorbidities, a nephron-sparing approach became the standard of care, particularly for tumors of less than 4 cm in size. The first laparoscopic nephrectomy in 1991 ushered in minimally invasive approaches to the treatment of kidney cancer, allowing patients to avoid the significant morbidity and recuperation of a flank incision [2]. The minimally invasive approach has evolved into complex laparoscopic partial nephrectomy and laparoendoscopic single-site surgery. With the intent of further reducing both the morbidity of treatment and minimizing damage to the remaining renal parenchyma, urologists introduced cryosurgery for the treatment of renal lesions in the 1990s [3, 4]. Subsequent series established feasibility and safety of cryoablation for small renal masses [5, 6]. Although the early cohorts of patients were treated via a laparoscopy-assisted approach, percutaneous cryoablation has become an acceptable alternative to the surgical excision of small renal tumors. This chapter will review the evolution, cryobiology, indications, technique, results, and complications of percutaneous cryoablation.

Evolution of cryotherapy as a cancer treatment

The concept of cryosurgery is not new and can be traced back to the mid 1800s when Dr Arnott first published his observations when using cold therapy to treat accessible advanced tumors [7]. He reported a decrease in the size of the tumors with reduction in drainage and pain. His method was displayed at the Great Exhibition in London [8]. From Dr Arnott's early work, interest in thermal therapy in the treatment of a variety of oncologic, dermatologic, and epithelial conditions grew, but was limited by the available technology. The first major advance was the commercial introduction of liquid nitrogen, which facilitated freezing to temperatures of –196° C [9]. The subsequent addition of copper cylinder discs immersed in liquid nitrogen allowed for greater tissue penetration, resulting in ablation depths of 4–5 mm as compared to 1–2 mm with carbon dioxide-based techniques [8]. Through the 1940s and 1950s, cryosurgery gained little attention primarily due to the limitation in technology, and research focused more on understanding the pathophysiology of cryoablation.

The next major breakthrough, which ushered the era of modern cryosurgery, was introduced by Cooper and Lee, who together developed an apparatus for automated circulation of liquid nitrogen within a cannula that could be inserted to ablate the basal ganglia in the treatment of involuntary movement disorders [10].

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Subsequent applications included ablation of pituitary tumors in patients with acromegaly [11].

Through the 1960s to the early 1980s, experience, interest, and instrumentation advanced, and cryosurgery expanded into urology in the treatment of the prostate (both benign and malignant), gynecology for inoperative cervical and uterine tumors, and ophthalmology for a variety of eye conditions. With the application of the Joule–Thomson effect, additional cryogens (including carbon dioxide and argon compressed gas) were available, resulting in the development of diverse instrumentation and smaller probes. Interest in cryosurgery began to wane in the early 1980s as other forms of treatment became favored and advances in cryosurgical instruments slowed.

The 1990s began the next resurgence of cryosurgical techniques as a result of three primary factors. First, endoscopic and laparoscopic instruments improved, facilitating the explosion of minimally invasive surgery. Second, next-generation cryosurgical devices cooled to lower temperatures, resulting in more reliable ablation, and vacuum-insulated probes became smaller in diameter. Finally and perhaps most importantly, the introduction of intraoperative ultrasound facilitated realtime monitoring of the ice balls, allowing for accurate and complete treatment of target lesions [12, 13]. More recently, integration of sophisticated realtime imaging techniques, including computed tomography (CT) and magnetic resonance imaging (MRI) into the surgical and interventional suite has resulted in the ability to percutaneously cryoablate target lesions in more difficult locations with less risk to surrounding tissues.

Mechanism of action

As early as the 1960s, it was recognized that one of the primary mechanisms of cryotherapy-induced cell death was direct injury secondary to intracellular and extracellular ice formation [14]. Intracellular ice formation occurs in close vicinity to the cryoprobe secondary to rapid cooling temperature changes. The rapid cooling results in intracellular freezing before water can diffuse out of the cell. Intracellular ice crystals can also develop at temperatures lower than −20°C regardless of the cooling rate. Although not well understood, intracellular ice crystals are thought to mechanically disrupt the nucleus and organelles, resulting in cell dysfunction and death. Recent studies suggest that mitochondrial injury from intracellular crystals may induce cellular apoptosis [15]. Further away from the probe where cooling rates are slower and minimum temperature is higher (between 0°C and −20°C), the bulk of direct cellular injury appears to occur through formation of extracellular ice crystals. The crystallization of the extracellular environment results in dramatically increased solute concentrations driving water across the cell membrane into the surrounding spaces. The cells then become osmotically dehydrated, causing disruption of the cellular membrane and breakdown of the protein machinery [16].

The degree of direct cell injury during the acute phase is affected by several thermal parameters, including the rate of cooling, minimum temperature achieved, duration of freeze, and rate of thaw [17]. Most *in vitro* studies show that rapid cooling rates achieve a higher degree of cell death; however, cooling rates *in vivo* can vary widely depending on the instrumentation and the properties of the target tissue. In reality, rapid cooling (>50°C/min) likely occurs only in close proximity to the cryoprobe. Therefore, given the variability in cooling rates, it is more important to achieve minimum temperature thresholds throughout the target tissue. Tatsutani *et al.* sought to quantify the relationship between thermal variables and cell destruction in prostate adenocarcinoma cell lines [18]. Their results indicated that for slower cooling rates, complete cell ablation was achieved by reaching a threshold of −40°C. The duration of freeze becomes a factor in the zones where the minimal temperature threshold is not achieved. In these areas with a temperature between 0°C and −40°C, longer durations allow for more complete osmotic dehydration of the cells as extracellular crystallization occurs. Finally, slow and complete thawing in between freeze cycles is recognized as a critical factor in achieving maximal cell ablation. Slow thaw facilitates cell injury by maximizing the increased extracellular solute effects and recrystallization (the process by which crystals fuse to form larger, more destructive crystals).

The second mechanism of cell death in cryotherapy is delayed tissue ablation secondary to changes in the microvasculature of the target tissue. The pathophysiology of delayed injury was first recognized by investigators studying the effects of frostbite and the resultant vascular changes [19]. The constellation of changes leading to tissue ablation occurs during both freeze and thaw. During the initial freeze, vascular flow ceases, resulting in hypoxia and direct cell injury. During the subsequent thaw, the tissue responds with a compensatory vasodilation and hyperemia. However, the cryotherapy-induced damage to the endothelial and microvessel wall results in increased capillary wall permeability, interstitial edema, platelet aggregation, and formation of the microthrombi [16]. The loss of endothelial cell junctions can be seen as early as 2h after a freeze–thaw cycle [20]. Most small vessels are thrombosed by 4h, with larger vessels by 24h. Together the changes result in widespread tissue ischemia, tissue necrosis, and eventual scar formation. Although it is difficult to measure the relative impact of direct cell injury (acute) versus vascular injury (delayed), most investigators suggest that the latter may be the more important factor in complete tissue cryoablation.

Since the beginning of modern cryosurgery, it has been recognized that repeated freeze–thaw cycles are critical to maximize cell destruction in the zone of ablation [21]. Chua and Ho developed an analytical model to simulate the effect of multiple freezing parameters on the efficacy of cryoablation and reported that a second freeze–thaw cycle may increase cell death by 50% as compared to a single cycle [22]. The improvement in cell death is seen at the periphery of the ablation zone where minimum temperatures may only reach –20° C to –30° C. Histologic studies in animals undergoing experimental cryosurgery have demonstrated that the second cycle increases the size of the ablation zone and enhances cell destruction [23–25].

In an effort to enhance the lethality of cryosurgery, recent investigations have focused on other mechanisms of cryo-induced cell death, including direct cell injury-induced apoptosis and the immunologic response. Grdovic *et al*. studied apoptosis pathways in liver tissue and found multiple products of apoptotic activation in the cytosol of cells in the ablation zone [26]. Wen *et al*. performed cryotherapy of lung adenocarcinoma implants in mice and found cell necrosis due to direct cell injury in the central zone of the tumor and activation of caspase 3 and poly-ADP ribose polymerase (PARP) in the peripheral zone [15]. They concluded that apoptotic pathways are more important in the peripheral zone of ablation where temperatures do not meet necrotic thresholds. With regards to the immunologic response, substantial infiltration by immune cells is seen after cryotherapy. However, there has been conflicting evidence regarding the impact of these immune cells on cell death [17]. More recent studies have focused on the potential of immunomodulation to augment cell death. For example, Jiang *et al*. and Clarke *et al*. reported enhanced lethality of cryoablation when combined with tumor necrosis factor-alpha (TNF-α) and TNF-related apoptosis-inducing ligand (TRAIL) [27, 28].

Indications and contraindications for percutaneous cryoablation

During the early experience, percutaneous cryoablation was reserved for small peripheral kidney tumors [4, 29]. However, improved interventional imaging and more experience have allowed expansion of indications to include tumors in more complex locations, including perihilar, endophytic, and neighboring adjacent organs. Although there are no specific size criteria, percutaneous ablation is generally indicated for tumors less than 4 cm in greatest diameter. Several studies have shown increased complication rates with larger tumors. Most urologists prefer the percutaneous approach for patients with significant comorbidities who may not be surgical candidates.

The contraindications for percutaneous ablation can be grouped into tumor-related and patient-related factors. Absolute tumor-related complications include tumors with vein thrombus, tumors with adjacent organ invasion, and tumors not safely accessible via percutaneous approach. Relative tumor-related contraindications include tumors larger than 3–4 cm, centrally located tumors, and tumors radiographically adjacent to neighboring organs (especially in previously operated upon kidneys). Absolute patient-related contraindications include uncorrectable bleeding diathesis, morbid obesity (unable to fit CT or MRI gantry), and severe medical comorbidity that limits the patient's ability to lie flat in the prone position. Relative patient-related contraindications include young age, hereditary kidney cancer syndromes (in which future kidney surgery may be anticipated), correctable bleeding diathesis, and solitary kidney.

Technique

Patient selection and preoperative evaluation

As with any surgical procedure, appropriate patient selection is a precursor for successful outcomes. Patients most suitable for percutaneous ablation are those with renal insufficiency, prior renal surgery, or medical comorbidity that increases risk of general anesthesia and surgery. Although some clinicians reserve ablation for elderly patients (>70 years old), we feel that age should be a relative factor in the recommendation for ablation. For example, we have offered percutaneous ablation even in younger patients (50–70 years old) with small, indeterminate lesions who are seeking definitive intervention. We strongly advocate the joint evaluation and participation by both the urologist and interventional radiologist. Patients should undergo routine presurgical testing, including complete blood count, basic metabolic panel, chest X-ray, and electrocardiogram. Coagulation studies are generally only required in patients with known or suspected bleeding diathesis. Most patients undergo the procedure under conscious sedation or monitored anesthesia care. However, patients with pulmonary disease may require general anesthesia with intubation and therefore, should undergo appropriate preprocedure pulmonary and anesthesia evaluation. Patients with intravenous contrast allergy should be prepped with prednisone and diphenhydramine in case contrast is necessary to image the lesion during probe placement.

Preoperative or concomitant biopsy

The role of percutaneous biopsy of kidney lesions has long been controversial. The emergence of active surveillance and percutaneous ablation has increased enthusiasm and more importantly, reinvigorated research in improving the value of biopsy (see Chapter 110). Historically, fine needle aspiration (FNA) biopsy suffered from a combination of low sensitivity and high false-negative rates. In a recent review, Volpe *et al*. found that large series of FNA biopsies reported sensitivity of 76–97% and nondiagnostic rates of 7–24% [30]. Core biopsies clearly improve on the accuracy of percutaneous biopsy, as demonstrated by two recent series. Wang *et al.* performed core biopsies on 110 patients and reported a sensitivity of 90.1% with histopathologic accuracy in 100% of the 34 patients who ultimately went on to extirpation [31]. Volpe *et al*. performed ultrasound/CT-guided core biopsies on 100 patients and reported 84% sensitivity and again 100% histopathologic accuracy in 20 patients who underwent subsequent extirpation [32]. Furthermore, histologic subtyping and grading was possible in 93% and 63%, respectively. The primary hesitation in performing more core biopsies is the concern for complications; however, the recent literature reports risk of tumor seeding as 0.01%, significant retroperitoneal hematoma as less than 2%, and mortality as 0.031% [30, 31]. With regards to percutaneous ablation, pathologic confirmation is useful in following patients post procedure, especially in the circumstance of imaging findings of recurrence. In addition, a biopsy will reveal less common diagnoses, such as sarcoma, renal lymphoma, or metastasis. As such, we feel that percutaneous biopsy by either core or FNA should be performed either prior to or at the time of percutaneous cryoablation. The recommendations of the Society of Interventional Radiology echo this statement [33].

Image guidance and probe placement

Percutaneous cryoablation of renal tumors can be performed under ultrasound, CT, or MRI guidance. All three modalities allow for accurate needle or probe placement for ablation. Ultrasound has the advantage for true realtime needle and probe placement. However, percutaneous monitoring of the ice ball is compromised due to acoustic shadowing from the advancing ice ball. Furthermore, tumors in complex locations, such as adjacent to neighboring bowel, are not suited for ultrasound guidance as the proximity of the adjacent structures is not readily evident sonographically. Some practitioners use ultrasound for initial probe placement; however, by far the most commonly used imaging modality for precise placement and monitoring during percutaneous cryoablation is CT scan. Its advantages include excellent anatomic resolution, reasonable monitoring of the ice ball, and opportunity for post probe removal imaging to detect significant bleeding complications. The disadvantages include the associated radiation exposure, inability to visualize certain endophytic lesions without intravenous contrast, and the lack of realtime imaging. The latter disadvantage could be overcome with the use of CT fluoroscopy; however, its widespread use is limited due to the significant increase in both patient and physician radiation exposure [34].

More recently with the introduction of compatible instrumentation, MRI has been employed for percutaneous cryoablation. The advantages of MRI include excellent anatomic resolution with the ability for multiplanar imaging; excellent monitoring of the ice ball, including its extension into perinephric fat; ability to visualize renal tumors without the need for contrast agents; and perhaps most importantly, the lack of ionizing radiation. The procedures are generally performed in open-gantry MRI scanners so there is no issue in patients with claustrophobia. The primary disadvantage is that most institutions do not have the capacity to have an MRI dedicated to interventional procedures. Also, many anesthesia monitoring devices such as electrocardiography (ECG) leads/wires are not MRI compatible.

We perform the vast majority of percutaneous cryoablation using CT imaging guidance. Although patients can be placed in multiple positions, we prefer to use the prone position as it is generally comfortable for the patient and, for most tumors, allows for the shortest distance from the skin to the kidney. For patients in whom prone positioning is not possible due to comorbidity, a lateral decubitus position can be employed. This position may also be advantageous for anterior renal tumors as the bowel displaces medially away from the kidney. Following positioning, an initial scan of the abdomen is performed with a radio-opaque grid on the skin over the ipsilateral kidney (Figure 112.1). Based on the location of the tumor and the corresponding marker on the skin grid, a localization needle is inserted to mimic the angle of probe insertion. The angle of insertion into the tumor does not appear to affect the efficacy of ablation [35]. However, the angle of the probe should be directed away from the collecting system for tumors abutting the collecting system (Figure 112.2). Animal studies have suggested that freezing into the collecting system is associated with significantly increased risk of urine leak if there is a concomitant puncture of the calyx [36]. Once the needle is in place, the distance from the center of the tumor to the skin is measured. A biopsy needle or cryoprobe is inserted percutaneously and advanced on the same trajectory half the distance to the tumor. A repeat scan is performed confirming the proper angle of the probe. The probe is then advanced into the tumor. Once the initial probe is in place, additional

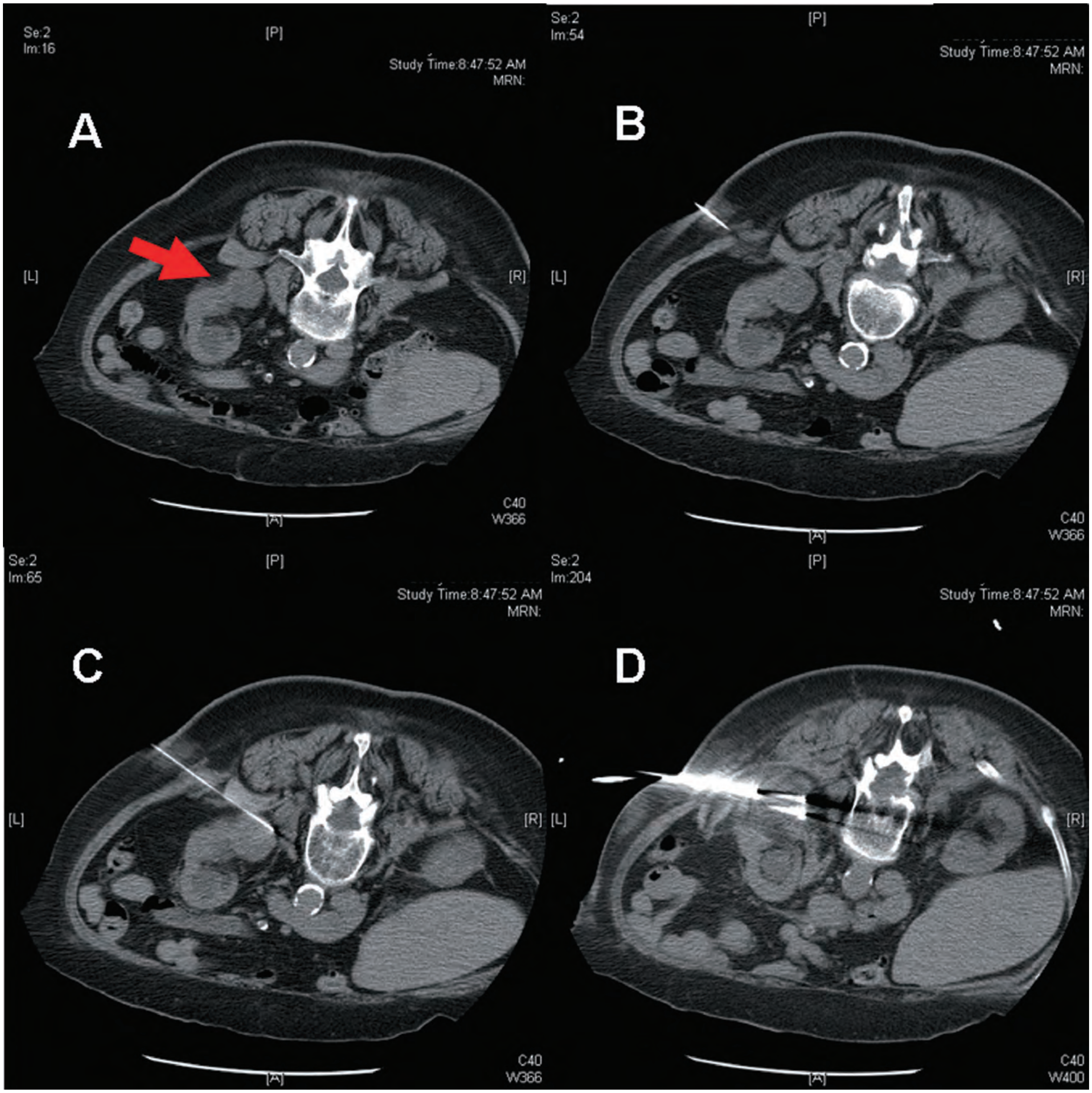
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Figure 112.1 Needle localization and probe placement. (A) Noncontrast CT of the abdomen with lower pole left renal mass (arrow). (B) Localization needle placed into the subcutaneous space positioned at an angle directed at the mass. (C) Using the localization needle as a guide, the initial probe is inserted into the inferior aspect of the tumor. (D) Once all probes are in position, the freeze–thaw cycle is initiated and the ice ball is monitored.

probes, depending on the size of the tumor, can be inserted in parallel to mold an appropriate ablation zone.

Cryoprobes

During the early history of modern cryosurgery for renal tumors, the smallest liquid nitrogen-based cryoprobes were 3 mm in diameter. The development of vacuum-insulated argon gas-based systems using the Joule–Thompson effect resulted in significantly smaller diameter probes. Today, the two primary manufacturers of argon-based cryotherapy systems, Galil Medical Inc (Arden Hills, MI, USA) and HealthTronics Inc (formerly Endocare Inc; Austin, TX, USA), offer probes as small as 17G (1.74 mm). Probes are constructed in different

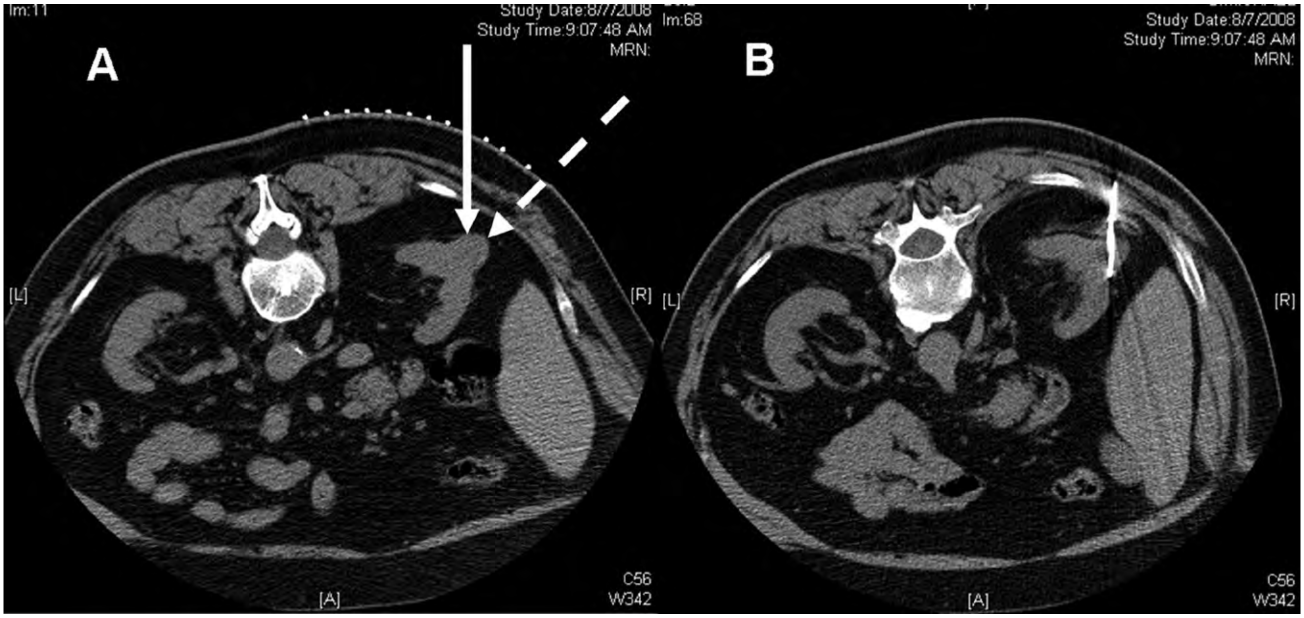

Figure 112.2 Angle of probe insertion should be directed away from the collecting system. (A) CT scan abdomen showing a right renal mass. The dashed arrow shows the improper angle of probe insertion while the solid arrow shows a better angle of approach to avoid puncture into the collecting system. (B) Final probe placement into the renal lesion.

lengths to accommodate different tumor access lengths. Due to the size of the probe handles, close parallel probe placement can sometimes be difficult. In these cases, the use of multiple length probes can circumvent the difficulty of several probes in close proximity. Probes are also designed to produce ice balls of different sizes and a variety of configurations, i.e. spherical versus oblong [37]. Therefore, depending on the size and location of the renal tumor, the urologist and interventional radiologist can plan the number of probes needed and the size/configuration with the goal of sculpting the ice ball to safely encompass the tumor and a margin of normal renal parenchyma.

Monitoring of the ice ball

Critical to successful percutaneous ablation of renal tumors is the monitoring of the ice ball to ensure an adequate and safe zone of ablation. During laparoscopic cryoablation, ultrasonography on the contralateral surface of the kidney can reliably visualize the hyperechoic leading edge as the ice ball expands [38]. However, ultrasound guidance during percutaneous ablation is more limited. On the other hand, CT and MRI provide excellent imaging of the expanding ice ball (Figure 112.3). Our practice is to scan the patient at 4 min and 9 min of each 10-min freeze cycle to ensure that the zone of ablation extends at least 5 mm beyond the edge of the tumor. Published isotherms indicate that lethal temperatures lower than −20° C are found 3–5 mm inside the edge of the advancing ice ball. Of course, this is predicated on the fact that the manufacturer-established isotherms, which were developed in nonhuman, nonliving, nonsolid sources, are accurate [39]. Young *et al*. sought to independently measure isotherms in both an *ex vivo* and *in vivo* model [40]. Their results were somewhat surprising in that temperatures 5 mm distal to the tip of the probe *in vivo* were as high as 19–27° C. The authors concluded that the tip of the probe should be advanced 5 mm beyond the edge of the tumor to ensure adequate lethal cooling temperatures. In addition, isotherms may be altered when treating tumors located adjacent to large vessels secondary to a heat sink effect, which results in warmer than expected temperatures. This effect is caused by convection heat transfer from circulating 37° C blood in the neighboring vessel. Given the uncertainty of isotherms, some urologists advocate the routine use of intraparenchymal thermal sensors to monitor the temperature adjacent to the tumor during ablation.

Maneuvers to limit collateral damage

The most dreaded and difficult complication of percutaneous cryoablation is injury to adjacent structures, such as the ureter, major renal vessels, paraspinal muscles, and the bowel. There are several techniques that can be used to increase the safe distance between the tumor and critical structures and therefore, to reduce the risk of iatrogenic injury. The most commonly used

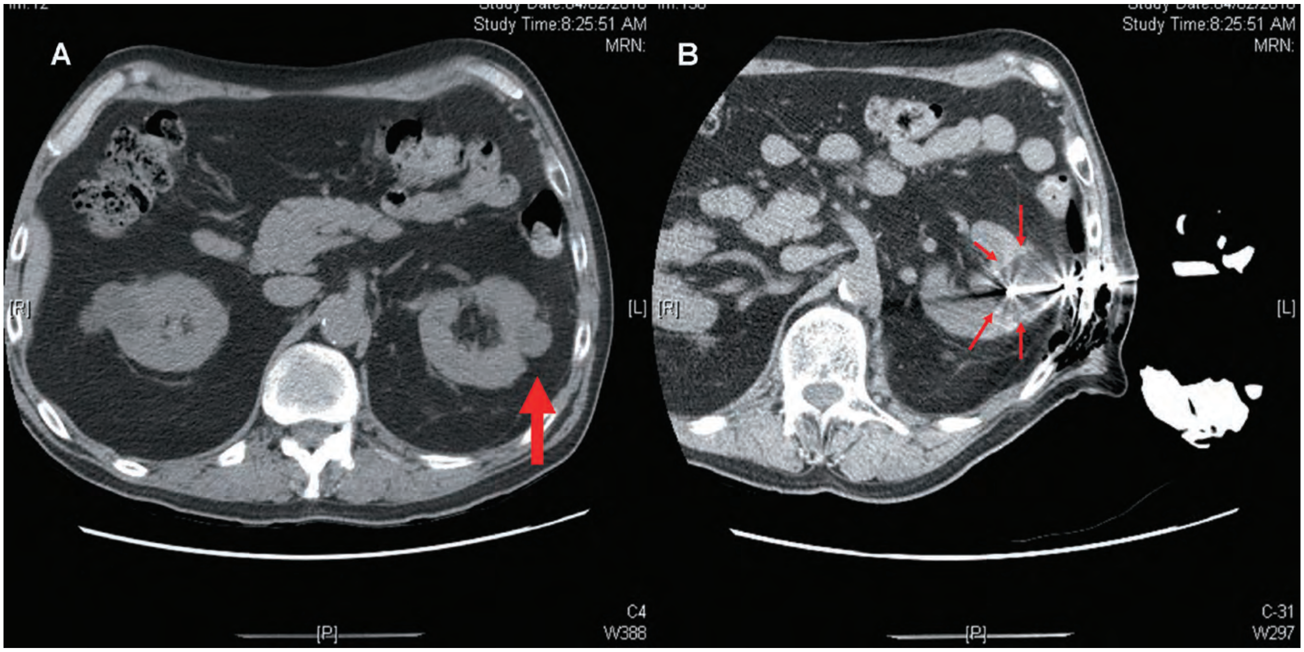

Figure 112.3 Monitoring of the ice ball using CT guidance. (A) Noncontrast CT of the abdomen shows a 2.3-cm mass in the lateral aspect of the left kidney (arrow). (B) Following cryoprobe insertion, CT image at 9 min of freezing shows the expanding ice ball as a region of decreased attenuation (marked by arrows).

technique is hydrodissection. A hollow bore needle is placed into the perinephric space between the kidney and the critical structure. Sterile water is then injected into the space, resulting in displacement of the organ (Figure 112.4). Arellano *et al*. retrospectively reviewed 36 ablation procedures in which hydrodissection was used and reported an increase in distance from an average of 0.36 cm to 1.94 cm [41]. Air can also be injected into the space and will track around the kidney, preferentially filling posterior spaces (for patients in the prone position). Ginat *et al*. retrospectively evaluated 11 percutaneous ablation cases in which displacement of the bowel was necessary [42]. In eight cases hydrodissection alone was successful (mean 105 mL injected), one case required hydrodissection with external torque on the ablation probe, and in two cases hydrodissection was completely unsuccessful. Overall, they reported a mean displacement of 1.7 cm, including the two failed cases; in the latter two cases, a 4-cm angioplasty air-filled balloon was placed between the bowel and tumor. Some centers have utilized diluted iodinated contrast for hydrodissection to better visualize the interceding fluid [43].

Lower pole medial tumors are often in close proximity to the ureter. Another method besides hydrodissection to protect the ureter is cystoscopic placement of a ureteral catheter. The catheter is then connected to a warm fluid source with slow irrigation. The warm infusion protects the ureter from thermal damage [this technique can be used for radiofrequency ablation (RFA) with cold fluid irrigation]. Ureteral catheters with cold water infusion were inserted by Cantwell *et al*. in 17 patients undergoing RFA within 1.5 cm of the ureter; at a mean follow-up of 14 months, they reported no strictures or hydronephrosis [44]. Another method of displacement away from the ureter is by external probe retraction. Following probe placement into the tumor, a "stick" freeze is performed (temperature at –10° C), resulting in a small ice ball at the tip of the probe. Externally, the probe is retracted either manually or by placing a bolster (such as a rolled towel) between the patient's skin and the probe handle. This maneuver can increase the distance as much as 10–12 mm, as demonstrated by a recent report in three cases [45]. We have used this technique to rotate tumors away from the renal artery as well (Figure 112.5).

Probe removal and hemostasis

Once the double freeze–thaw cycle ablation is completed, the probes are carefully removed to avoid renal fracture and postprocedure hematoma. We recommend that probes are not removed until the temperature reaches 25–28° C to ensure that no residual ice ball remains. In order to reduce the risk of postprobe removal hemorrhage, some investigators have advocated the injection of coagulants or tissue sealants [46]. However, this requires the use of a coaxial system or sheath during probe placement.

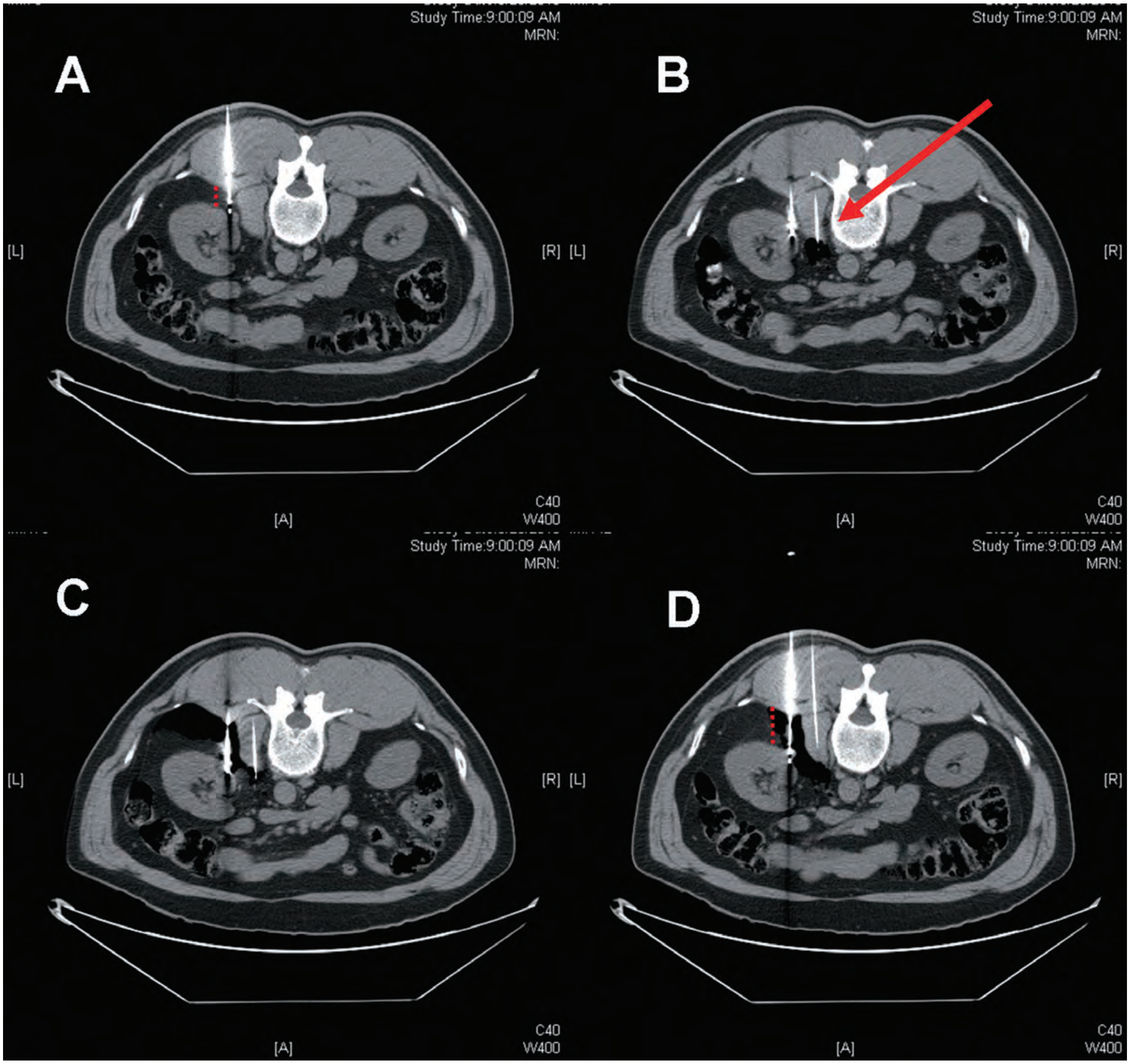

Figure 112.4 Pneumodissection to displace neighboring organs. (A) Probe placement into small posterior left renal lesion abutting the psoas muscle (dotted line). (B) An 18G spinal needle is advanced into the retroperitoneal space and air is injected (arrow). (C) Pneumodissection moves the kidney off the psoas muscle. (D) At the beginning of the freeze–thaw cycle, the distance between the kidney and psoas muscle has increased (dotted line) to reduce the chance of significant thermal injury to muscle.

Oncologic and functional outcomes

Percutaneous renal cryoablation was first reported in 1995 by Uchida *et al.* in two patients with metastatic renal cell carcinoma (RCC) [4]. An 8.4-mm probe was inserted into the center of the tumor and cooled to –20°C. Subsequent scans revealed a 68% and 20% reduction in the tumor size and remarkably, both patients experienced temporary significant improvement in functional status. Following this report, investigators studied renal cryoablation as a curative treatment for small renal masses. Initially, a laparoscopy-assisted technique, in which the kidney was mobilized and the tumor isolated, was employed. The probe was inserted under direct vision and laparoscopic ultrasound was used to monitor the ice ball. Several single-institution series of laparoscopic cryoablation have since demonstrated excellent long-term oncologic efficacy [47, 48].

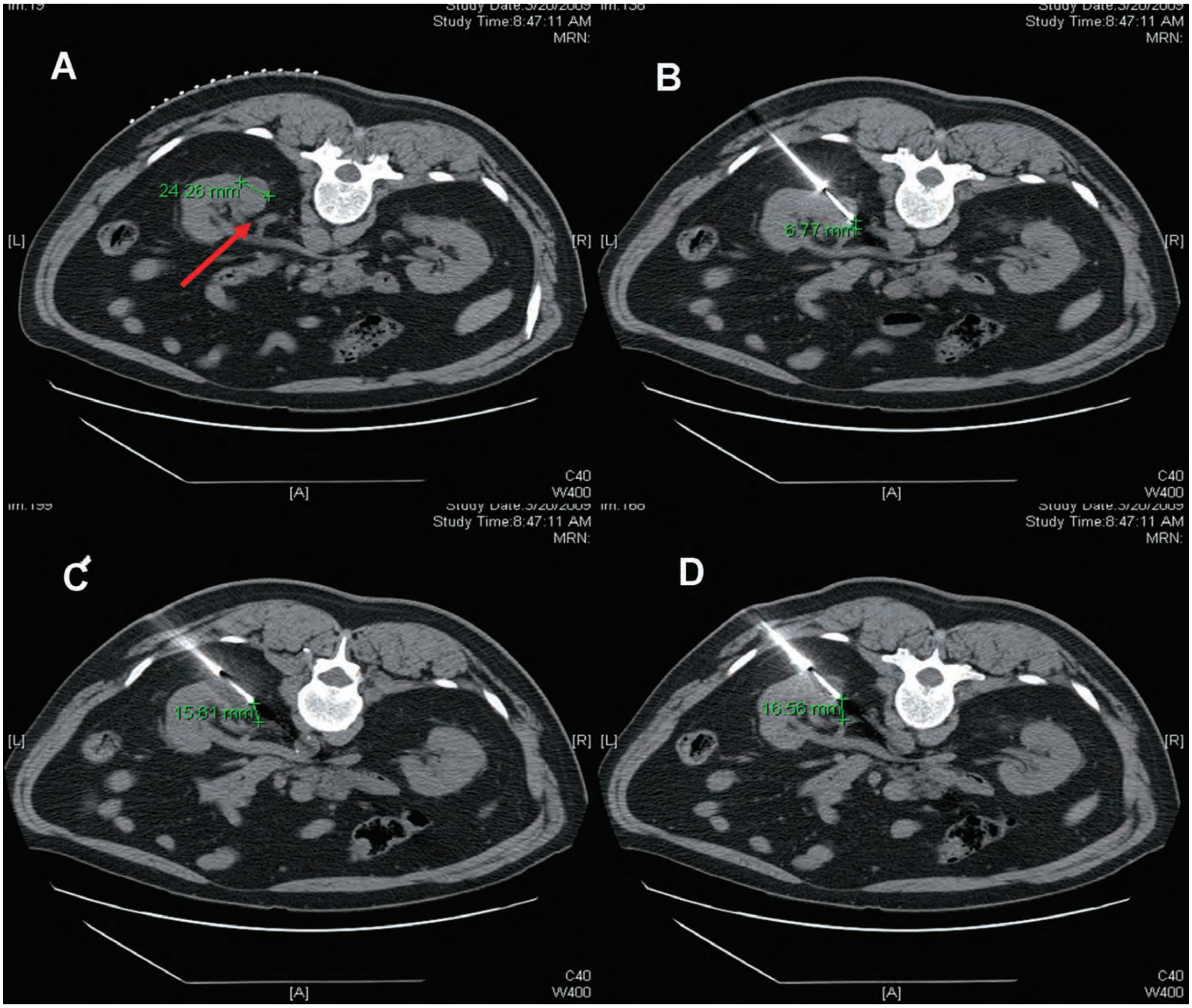

Figure 112.5 External manual displacement. (A) Noncontrast CT abdomen shows a 2.4-cm left posterior medial mass in close proximity to the renal vasculature (space marked by arrow). (B) Following cryoprobe placement into the tumor, the distance between the edge of the probe and renal vessel is 6.7 mm. (C, D) With the probe in "stick" mode (−10° C), external manual displacement with a rolled towel increases the distance between probe and renal vessel to 16.5 mm. Cryoablation is safely performed without injury to vasculature.

Given the success of laparoscopic ablation, percutaneous renal cryoablation has become more accepted and is now being used to treat more complex tumors.

Table 112.1 lists the largest percutaneous renal cryoablation series reported in the literature to date. Although intermediate and long-term follow-up is still necessary, early results show excellent oncologic efficacy. Overall, approximately 80% of the treated lesions in the reported studies were biopsy-proven RCC with an average size of 2.8 cm. Local recurrence or treatment failure rates have been reported to be between 2.5% and 25% at a mean follow-up of 7–30 months. For patients with solitary kidneys, Weisbrod *et al*. reported similar excellent short-term oncologic results with initial technical success in 32 of 35 patients (92%) and no evidence of recurrence in the 32 successfully treated patients at a mean follow-up of 14 months [49]. Percutaneous cryoablation has been successful even for larger tumors. Schmit *et al*. reported results in 108 patients with 110 tumors greater than 3 cm in size [50]. Overall, 107 of the 110 tumors were completely treated with a single ablation, as demonstrated by a lack of contrast enhancement at the 3-month CT scan. Follow-up was available in 82 patients, and at a mean follow-up of 14 months no patient demonstrated local tumor recurrence (as evidenced by residual contrast enhancement on CT or MRI).

Table 112.1 Recent larger series of patients undergoing percutaneous cryoablation of renal masses.

Study	Number (patients, lesions)	Mean age (years)	Mean tumor size (cm)	Rate of biopsy–confirmed malignancy (%)	Mean follow-up (months)	Recurrence/ treatment failure (%)	Cancer-specific survival (%)	Major complication rate (%)
Shingleton and Sewell 2001 [29]	20, 22	58	3.2	NR	9.4	5	NR	0
Permpongkosol *et al*. 2006 [64]	21, 23	71.5	2.1	100	12.3	17.4	100	0
Littrup *et al.* 2007 [65]	36, 36	67.3	3.3	100	13.1	11.1	100	6
Finley *et al.* 2008 [66]	18, 19	NR	2.7	67.40	12.8	5.65	NR	5.5
Georgiades 2008 [68]	40, 40	67	3.0	100	7	2.5	NR	16
Hinshaw *et al.* 2008 [56]	30, 30	67	2.1	NR	14.5	10	100	0
Derweesh *et al.* 2008 [54]	26, 26	69.7	3.1	69.20	NR	11	100	NR
Atwell *et al.* 2008 [67]	110, 115	72	3.3	70	13.3	3	97	6
Malcolm *et al.* 2009 [48]	20, 20	66.5*	2.3*	62*	30*	25	100*	NR
Totals	**321, 331**	**67.4**	**2.8**	**81.2**	**14.1**	**10.1**	**99**	**4.8**

*From combined series of laparoscopic and percutaneous cryoablation.
NR, not reported.

One of the most controversial topics in renal tumor cryoablation is defining local recurrence or treatment failure. Currently, the standard of care is to follow patients with contrast-enhanced cross-sectional imaging. Any residual enhancement is considered suspicious for undertreatment or recurrence. Most reports describe either focal nodular enhancement or a crescent-shaped enhancement at the border of the ablation zone. This was confirmed in a study by Weight *et al*. in which post-treatment biopsy following cryoablation was found to highly correlate with post-treatment imaging findings [51]. The timing of imaging is also debated. Our practice is to perform the first imaging 4–6 months after treatment. Earlier imaging may show residual enhancement but may not be indicative of treatment failure. Porter *et al.* reported that a high proportion of studies showing enhancement within 3 months of cryoablation resolved by 6-months [52]. Typically, in contrast to RFA lesions, tumors treated by cryoablation undergo involution over time with a decrease in the size of the treated area. The current recommendations from the Society of Interventional Radiology are for consideration of early imaging (1 week to 1 month) to confirm complete treatment (i.e. the ablation encompasses the entire tumor) and subsequent imaging by either CT or MRI at regular intervals to confirm treatment efficacy [33].

The management of local failures or recurrences is another debated topic. Breda *et al*. performed a review of the literature and found that 60–75% of local failures are treated with repeat ablations with good success [53]. There are also frequent reports in the literature of patients with post-treatment enhancement on imaging who are followed conservatively; however, there are no long-term studies to determine whether these patients are at risk for distant failure. Finally, salvage extirpative surgery is always an option. Our experience has been that postablation surgery is difficult due to extensive scarring and desmoplastic reaction around the treatment site. Nephron-sparing salvage surgery can be performed in selected cases, but many patients will require nephrectomy.

Functional outcomes

Overall, the functional outcomes following percutaneous cryoablation are excellent. Most series report an average hospital stay of 0–1 days with relatively quick return to baseline activity level. Two single-institution retrospective studies comparing laparoscopic cryoablation to percutaneous cryoablation reported significantly lower length of stay, decreased narcotic use, and faster return to activity [54, 55]. Furthermore, Hinshaw *et al*. reported 40% lower hospital charges for patients undergoing percutaneous versus laparoscopic cryoablation [56]. With regards to renal functional outcome, no series in the literature has reported significant changes in post-treatment creatinine. Specifically, in two different reports of cryoablation in solitary kidneys, neither study found a clinically significant change in post-treatment serum creatinine [49, 57].

Complications

Table 112.1 also shows the major complication rates as reported in these series of patients, with a range of 0–6%. Minor complications can occur in up to 25% of patients with most not requiring specific treatment other than observation. The two most common complications are flank pain and clinically significant hematoma. Flank pain can result from thermal injury to the paraspinal and psoas muscles during treatment. The pain is generally self-limited and managed with narcotic pain medications. More prolonged and significant pain can occur with thermal damage to the genitofemoral nerve or intercostal nerves innervating the abdomen. Fluid hydrodissection is helpful to move the zone of ablation off the posterior abdominal wall to reduce this risk (see above).

Hematoma and hemorrhage is by far the most common nonpain-related complication. Most series report post-treatment transfusion rates of less than 5%. The risk of hematoma directly correlates with increasing size of the tumor and number of probes [58, 59]. Our experience has been that tumors larger than 3 cm have a significantly higher post-treatment hemorrhage risk as compared to smaller tumors. The rare patient with actively ongoing post-treatment hemorrhage most often does not require surgical exploration; in contrast, angiogram with coil embolization of the offending vessel is successful in virtually all cases.

Bowel injury from thermal injury to the bowel wall can be a devastating complication. Most cases present in a delayed manner with abscess and fistula formation. Although conservative management by percutaneous drainage has been reported, most patients will require laparotomy with or without bowel resection [60]. Ureteral injury is a relatively rare complication of cryoablation (more commonly reported with RFA) and manifests as a ureteral stricture and hydronephrosis on follow-up studies. These injuries can be prevented by pretreatment placement of a ureteral catheter with warm saline irrigations (see above). Although the strictures can be managed temporarily by stenting, long-term resolution is achieved only by surgical reconstruction.

Pneumothorax is another relatively common complication that can occur during access to upper pole tumors. Specific attention to the lung bases during treatment imaging can identify if a pneumothorax has occurred. Most can be managed conservatively with serial chest X-ray; a chest tube is required only for large (>25%) or symptomatic occurrences.

Finally, urine leak/fistula is a rare complication that results from puncture injury of the collecting system followed by thermal ablation involvement of the injured calyx. This scenario occurs during the treatment of large tumors or those abutting the collecting system. Avoidance of calyceal puncture during probe placement is the primary preventive measure as ablation into the collecting system alone has been shown to be safe. Management of an urinoma centers on percutaneous drainage. As long as there is no distal obstruction, most urine leaks will resolve spontaneously.

Future directions and conclusions

Percutaneous renal cryoablation of small renal masses has become an accepted treatment modality not only for patients who are not surgical candidates but also for those seeking treatments with less morbidity and shorter recovery. Future improvements will center on improved realtime imaging capabilities to shorten treatment times and potentially improve treatment efficacy by improving the accuracy of probe placement. Haber *et al*. reported on initial experience with realtime ultrasonography fused with three-dimensional CT imaging in a porcine model to improve precision of percutaneous probe placement [61]. Investigators have already made significant strides in the use of automated devices and robotics for percutaneous needle placement into the kidney [62, 63]. In addition, longer follow-up studies are needed to demonstrate long-term oncologic efficacy in order for percutaneous cryoablation to become an equal alternative to partial nephrectomy.

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CHAPTER 113

Image-Guided Prostate Brachytherapy

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Introduction

In the era of routine prostate-specific antigen (PSA) screening, prostate cancer has become the most common cancer in men. In 2008, it was estimated that over 186 000 men would be diagnosed with prostate cancer, with only 10% of these men being diagnosed with high-risk prostate cancer [1, 2]. This shift toward low-risk disease, as well as younger age at the time of diagnosis, not only improves the potential outcomes of treatment, but also emphasizes the need to discuss treatment options within the context of quality-of-life outcomes. Long-term results have shown that oncologic control or "cure" is attainable with definitive treatment in a high percentage of cases. Currently surgical removal (prostatectomy) [3] and permanent prostate brachytherapy (PPB) [4] have demonstrated their ability to achieve similar and acceptable rates of control. Other treatment modalities, including external beam therapy using intensity-modulated radiation therapy (IMRT) [5], cryotherapy [6], and radiofrequency ablation (RFA) [7] also appear to be effective in select cases, although long-term data are lacking. This chapter reviews outcomes of PPB in the management of prostate cancer.

History of prostate brachytherapy

Prostate brachytherapy predates radical prostatectomy, having been introduced in the 1920s with radium needle implants. Later, in the 1960s, radioactive gold seeds were used to treat prostate cancer [8]. Outcomes were poorly reported in the pre-PSA era and the complexity of working with radioactive isotopes hampered its acceptance as a treatment modality. Interest in brachytherapy re-emerged in the 1970s when Whitmore and associates at Memorial Sloan Kettering in New York established an open, retropubic approach using iodine-125 seeds [9]. However, trying to uniformly implant the exposed gland did not prove to be the best way to achieve homogenous dose coverage. The 15-year outcomes were disappointing, with only 21% of patients reported to be controlled.

A resurgence of prostate brachytherapy occurred in the 1980s due to the transperineal approach developed by Holm *et al.* [10]. The approach adopted in Seattle utilized a "pre-plan" to account for the seed placement, while in New York a more conservative approach was developed to limit the morbidity of the procedure by peripherally placing seeds to limit central hot spots [11]. Given the ability for realtime image guidance of implant *in situ*, excellent results have been obtained with PPB, and both approaches remain active to this day.

Patient selection

Implantation of the prostate is an attractive option because it concentrates treatment on the prostate and minimizes radiation exposure and morbidity to nearby organs, including the bladder, rectum, and small bowel. PPB is an outpatient procedure and the patient may resume 100% of physical activity within 24 h. The implant serves as the delivery mode of the isotopes, which decay over time and represent the actual treatment.

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Because PPB utilizes realtime ultrasound-based image guidance, this procedure is truly conformal and allows for high radiation doses to be delivered to the prostate. While the urethra remains central within the prostate and cannot be excluded from radiation exposure, newer approaches of PPB allow urethral sparing [12].

The ideal candidate for PPB is one with clinically confined disease, as is the case for patients considering radical prostatectomy. Risk stratification of disease by initial PSA value and Gleason score better predicts outcome and allows for treatment modification to account for those men with high-risk disease. Where the risk of extraprostatic disease is high, there is the need to combine PPB with external beam radiotherapy (EBRT).

PPB is associated with urinary bother that may be mild, or protracted and quite bothersome to the patient. Indwelling catheterization has been reported in 2–20% of patients following PPB. Higher rates of acute urinary obstruction date back to older techniques that failed to spare high doses centrally within the prostate. Other factors associated with increased postimplant urinary bother include a high initial International Prostate Symptom Score (IPSS) score (>7–10) and an enlarged prostate volume [13]. Patients with either or both of these factors need to be coached carefully before undergoing PPB. While it is customary to offer men with enlarged prostates a 3-month course of androgen ablation to reduce the prostate volume, there are data from Crook *et al*. suggesting that this does not reduce postimplant urinary bother [14]. Further, the long-term impact on potency of even a 3-month course of androgen ablative therapy needs to be considered. Patients with enlarged prostates and high IPSS scores may wish to consider EBRT as definitive treatment.

At present, an age-related bias exists within the urologic community, with younger patients being referred more often for radical prostatectomy than either radiation or no therapy. In a recent study from Shaprio *et al*., men younger than 60 years of age had identical biochemical outcomes at 5 and 10 years when compared to patients over 60 years of age, suggesting that age should not bias PPB as an option in younger men [15]. However, the risk of second primary cancers (SPCs) is an important consideration when offering PPB.

It is well known that radiation exposure is associated with SPCs. Several studies have shown an increased risk of bladder and colorectal cancer in men who were treated with radiation for prostate cancer [16, 17]. However, these studies were in patients treated with EBRT using older, conventional techniques. Brachytherapy, which is a highly conformal therapy, appears to have a lower SPC risk than EBRT [18, 19]. Nevertheless, this remains a valid concern and should be discussed with each patient.

Technical issues

PPB is currently performed as per Holm [10] via a transperitoneal approach with realtime ultrasound visualization of the prostate. Accurate placement of the needles is achieved with this technique and the isotopes are placed through them into the prostate. Outcomes following PPB clearly identify that implant quality relative to the delivered dose is key to a successful outcome. Several approaches are used for seed implant, but the key to success is more the implant quality than the technique.

One approach calls for linked or stranded seeds to be placed based on a “pre-plan” of the implant. One advantage of this technique is that the seeds cannot migrate from the prostate.

Another approach is a realtime, adaptive implant, using an interstitial gun to place each seed. Using intraoperative software, a “forward” plan can be generated based on the exact prostate volume and location. With the dynamic–adaptive implant approach, there is less of a learning curve for physicians and centers starting PPB programs [20]. Also, with dynamic and adaptive assessment, fewer sources can be used while maintaining a high quality implant. Use of fewer seeds offers an opportunity for reducing both the rectal and urethral doses while still achieving adequate prostate coverage. Outcomes have identified less urinary bother with this approach.

^{125}I was the isotope used at the time of the Whitmore implants and it continues to be used for PPB. In the early 1990s, palladium-103 was introduced. Given its shorter half-life, it was postulated that ^{103}Pd would become the preferred isotope for tumors of higher Gleason score, because of their faster tumor doubling time [21]. In 2003, cesium-131 was introduced as a third isotope for PPB. ^{131}Cs has even a shorter half-life than ^{103}Pd, which has the advantage of a shorter period to follow radiation exposure precautions following the implant. Nevertheless, there have been no data to date to suggest that isotope choice should be based on tumor grade or prostate cancer doubling time. In a recent abstract of retrospective data, Cho *et al*. reported an advantage for ^{103}Pd over ^{125}I [22].

Results

Studies reporting long-term outcomes following PPB are now mature, longer than 10 years in many men, but without randomized data it is difficult to compare PPB to EBRT or radical prostatectomy. However, using PSA surrogates to define a successful outcome, it appears that PPB is at least equivalent to radical prostatectomy and perhaps slightly better than EBRT.

To delineate outcomes in men treated with radiation, a recent study from the University of California at San Francisco (UCSF) compared endorectal magnetic resonance spectroscopy imaging (eMRSI) responses between PPB and EBRT. For each parameter assessed, PPB outperformed EBRT in the median time both to spectroscopic evidence of disease ablation (24.8 and 32.2 months, respectively) and to nadir PSA (38.0 and 52.4 months, respectively) [23].

Long-term data in excess of 10 years support the use of PPB in the definitive treatment of low-risk prostate cancer. Potters *et al*. have reported a 12-year biochemical control rate (bNED) of 81% in a cohort of 1449 patients [4]. Freedom from biochemical recurrence for low-risk patients was 91%. Similarly, Grimm *et al*. showed that the PSA progression-free survival at 10 years was 87% for low-risk patients [24]. While younger patients look for longer-term outcomes, it must be remembered that for PPB, radical prostatectomy, and EBRT, outcomes that exceed 10–15 years are pushing against the early experience of PSA screening. Stage and grade migration over time may make long-term data less relevant to the current patient.

Outcomes for men with low-risk disease are excellent, with bNED rates greater than 90% at 8–12 years [4]. In several studies, implant quality as measured by the D90 dose (the radiation dose that covers 90% of the prostate volume) correlates with outcome. Therefore, the importance of implant quality needs to be emphasized.

For patients with intermediate-risk prostate cancer, Blasko *et al*. identified that the addition of EBRT to PPB was no better than PPB as monotherapy [25]; 5-year biochemical success rates were 85% versus 84%, respectively. Potters *et al*. also failed to identify an advantage of adding EBRT on Cox regression analysis of intermediate-risk patients [4]. One hypothesis is that poor implant quality, as measured by the D90 dose, can be compensated for by the addition of EBRT. With new techniques, such as dynamic–adaptive PPB, the D90 dose can be controlled intraoperatively, and further negates the need for combined therapy, especially in low- and intermediate-risk patients.

A predictive model for a postimplant nomogram for prostate cancer recurrence at 9 years has recently been reported from a large multi-institutional analysis of 5889 PPB patients [26]. This study further confirmed the significance of implant dosimetry for predicting outcome. Unique to predictive models, this nomogram may be used *a priori* to calculate a D90 dose that likely achieves a desired outcome with further validation. Thus, a personalized dose prescription can be calculated for each patient.

Although the treatment of high-risk prostate cancer is beyond the scope of this review, there appears to be both a dose and radiation field effect associated with PPB. In a multicenter analysis of 3928 patients, Stone *et al*. found that patients with high-risk prostate cancer benefited the most from an escalation in the biologic equivalent dose (BED) compared to the dose typically prescribed to patients with low-risk prostate cancer [27]. Additionally, a radiation field effect was suggested in a phase III trial (RTOG 9413), which demonstrated whole pelvic radiation with a cone-down or boost to the prostate was superior to local field radiation [28].

Many of the side effects seen with brachytherapy are associated with radiation exposure of the urethra, bladder, and rectum. These side effects can have serious quality-of-life implications, and brachytherapy requires informed consent from the patient.

In a prospective analysis of the quality of life of patients undergoing primary treatment for prostate cancer, Sanda *et al*. found that patients undergoing brachytherapy had a significant detriment in urinary irritation or obstruction scores compared to baseline [29]. As noted, factors associated with a greater detriment in urinary irritation or obstruction included a large prostate size and a high IPSS score. In the Sanda *et al.* study, these factors were not controlled for, suggesting that patient selection remains important. Similar to patients treated with EBRT and radical prostatectomy, PPB patients were found to have detriments in the domains of sexual function, urinary incontinence, bowel or rectal function, and vitality when compared to baseline. Changes in these domains were found to have a subsequent impact on the patient's satisfaction with the overall outcome of the treatment. Yet, for the sexual domain, PPB patients performed better than those treated with EBRT and radical prostatectomy [29].

Given the impact of erectile dysfunction on quality of life in an ever-younger cohort of newly diagnosed prostate cancer patients, it is vital to discuss the impact of sexual function with each patient. In a recent retrospective analysis Seideman *et al.* demonstrated a potency preservation rate of 66.4% at 9 years among males under the age of 60 undergoing PPB [30].

Comparative effectiveness and value

Recently, the Institute for Clinical and Economic Review (ICER) published their analysis of prostate brachytherapy versus IMRT EBRT or proton beam therapy (PBT) [31]. This analysis examined a total of 166 studies and found large differences in lifetime cost, with brachytherapy having 30% and 60% lower costs than IMRT EBRT and PBT, respectively [brachytherapy US$29 575 with 13.90 quality-adjusted life years (QALYs); IMRT EBRT US$41 591 at 13.81 QALYs; PBT $72 789 at 13.70 QALYs).

The evidence-based rating matrix assessment used by the ICER combines a rating for comparative clinical effectiveness and a rating for comparative value. Its comparing IMRT and brachytherapy identified a comparable clinical effectiveness of brachytherapy versus IMRT and an enhanced comparative value of brachytherapy versus IMRT. The results from this decision–analytic model suggest that brachytherapy is likely to be less expensive and result in slightly improved quality of life for a general population of patients compared to IMRT or PBT [31].

Conclusions

PPB is an established and cost-effective treatment for localized prostate cancer. Although randomized studies comparing PPB to other treatment modalities such as EBRT and prostatectomy are lacking, acceptable long-term outcomes in thousands of brachytherapy patients have been described. Given the overall prognosis of men with prostate cancer, coupled with the efficiency and durability of PPB, it is hard to make an argument for patients being treated by experimental radiation modalities outside of a protocol. While PPB needs to be selected carefully, based on IPSS score and prostate size, as well as other comorbidities, it remains a mainstay in the arsenal for prostate cancer. Given its cost–benefit advantage over more expensive radiation therapy modalities, brachytherapy should be the primary modality for men requiring radiation treatment for prostate cancer.

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CHAPTER 114

Image-Guided External Beam Radiotherapy

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Introduction

External beam radiotherapy (EBRT) is a targeted treatment that relies on imaging to provide surrogates for areas of interest, such as tumors, in order to focus the radiation beam. The quality of treatment depends on the imaging used to plan and deliver the treatment. As a result, improvements in the delivery of radiation therapy have been primarily based on advances in imaging modalities and the ability to incorporate these into the planning and delivery of treatment. Recent examples include computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET). In addition, computer technology has made it easier to incorporate an increasing number of customized beams, which allow the radiation dose to be further concentrated in the area of interest. The advent of these high-quality imaging techniques coupled with the use of computerized treatment delivery have enhanced the accuracy of delivering radiation dose to a target to within millimeters and are the hallmarks of intensity-modulated radiation therapy (IMRT).

Traditional radiation treatments generally use wide margins to accommodate potential movement or uncertainties during a treatment course. Doses are often limited due to the exposure of radiosensitive nearby structures. With more precise treatments, the dose to a target structure can be increased while reducing the dose to a neighboring critical structure. Certain areas, such as the brain, are particularly amenable to these types of treatments because movement is minimal or can be easily controlled. Many other parts of the body are prone to movement with loss of sub-centimeter accuracy with, for example, casual breathing. In addition, tumors can change, either shrinking or actually growing during the treatment course. These movements and changes result in reduced accuracy and either underdosing the target or overdosing nearby critical structures. Treatments can be replanned multiple times during a treatment course for a target that changes in size; this is referred to as image adaptive radiation therapy (IART). However, this process is currently in the early stages and can be labor intensive. For targets that maintain the same size but are more prone to movement, various methods may be used to compensate for that movement; these are known as image-guided radiation therapy (IGRT). IGRT is particularly useful for treatment of prostate cancer, where the target size is relatively stable but is prone to movement. These techniques allow for dose escalation, which has been shown to improve the outcome of localized prostate cancer. Despite higher doses, the increased accuracy allows for tighter margins to be used, resulting in low morbidity. This chapter details the use of IGRT for the treatment of prostate cancer.

Prostate cancer

Epidemiology

Prostate cancer has become the most common cancer in males based on Surveillance, Epidemiology, and End Results (SEER) data. In 2010, 217 730 cases were expected in the USA. Between 1999 and 2005, 92% of cases were

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diagnosed in the locoregional stages, for which the 5-year relative survival approaches 100%. An annual decrease of 42.4% between 2000 and 2006 reflects the decreased rates of detection and fewer undiagnosed cases resulting from the widespread use of prostate-specific antigen (PSA) screening in the 1980s and 1990s. Mortality has been declining since 1990, reflecting the use of screening PSA and improvements in treatment [1].

Screening

The American Urological Association (AUA) recently recommended two notable changes to prostate screening practice [2]. First, the age for obtaining a baseline PSA was lowered from 50 to 40 years, the rationale being that PSA screening is more specific for younger men and a better predictor for future development of prostate cancer than either family history or race. Second, the decision to obtain a prostate biopsy should not be based solely on a PSA above the threshold value but should be multifactorial, including digital rectal examination, free and total PSA, PSA velocity, PSA density, patient age, family history, ethnicity, prior biopsy history, and comorbidities [2]. Recently, published randomized trials comparing the mortality outcomes of a screened group versus a nonscreened group showed conflicting results [3, 4]. However, both studies suggested a high rate of overdetection and overtreatment. Therefore, the recommendation emphasizes an informed discussion of the risks and benefits of prostate cancer screening prior to biopsy, and the option of active surveillance instead of treatment for certain patients with prostate cancer.

Risk stratification

Once the diagnosis of prostate cancer is made, a staging work-up ensues in order to provide additional prognostic information for risk stratification, which may assist in management decisions. The National Comprehensive Cancer Network (NCCN) Version 1.2010 provides recurrence risk stratification among patients with clinically localized disease based on PSA level, Gleason score, clinical stage, and biopsy specifics (Table 114.1). The American Joint Committee on Cancer (AJCC) has recently incorporated PSA and Gleason score into a stage/prognostic group system (Table 114.2), while the TNM system for clinical and pathologic staging remains the same [5]. A CT scan may be obtained to assess clinically apparent adenopathy, but is generally not required for a PSA less than 25 ng/mL because the yield is too low to warrant its routine use [6]. Similarly, a bone scan may be obtained to determine the presence of bone metastases, but it is not generally required for a PSA less than 20 ng/mL [7]. Surgical lymph node staging is also considered unnecessary for the low-risk patient because the yield is low [6], and it is probably not necessary for the high-risk patient either because of the increasing use of pelvic nodal irradiation.

Table 114.1 Prostate cancer recurrence risk according to the National Comprehensive Cancer Network (NCCN) Practice Guideline in Oncology.

Very low
T1a
Gleason < 6
PSA < 10
<3 positive cores
PSA density < 0.15 ng/mL/g
<0% cancer in each core
Low
T1–2a
Gleason 2–6
PSA < 10
Intermediate
T2b–T2c or
Gleason 7 or
PSA 10–20
High
T3a
Gleason 8–10
PSA > 20
Very high
T3b–T4

External beam radiation therapy for prostate cancer

Patient selection

Patients with disease localized to the prostate without evidence of lymph node or distant metastasis may be candidates for EBRT. There are relatively few general contraindications to the use of radiation therapy for treatment of definitive disease. These include prior treatment with pelvic radiation therapy and presence of active autoimmune disease, particularly scleroderma and lupus. Inflammatory bowel disease may be considered a relative contraindication for patients undergoing pelvic node irradiation, since treatment may be poorly tolerated [8, 9], but it is considered safe for patients undergoing treatment to the prostate alone [10]. AJCC Group 1 patients may be treated with EBRT alone or a brachytherapy implant (see Chapter 113) with the possible rare exception of patients with an unknown PSA or Gleason score. Patients with Group 2–3 disease are usually candidates for EBRT or the combined approach of a brachytherapy implant and reduced-dose EBRT.

Table 114.2 Prostate cancer anatomic stage/prognostic group according to the American Joint Committee on Cancer Prostate Cancer.

Group	T	N	M	PSA	Gleason
I	T1a–c	N0	M0	PSA < 10	Gleason ≤ 6
	T2a	N0	M0	PSA < 10	Gleason ≤ 6
	T1–2a	N0	M0	PSA X	Gleason X
IIA	T1a–c	N0	M0	PSA < 20	Gleason 7
	T1a–c	N0	M0	PSA ≥ 10–<20	Gleason ≤ 6
	T2a	N0	M0	PSA < 20	Gleason ≤ 7
	T2b	N0	M0	PSA < 20	Gleason ≤ 7
	T2b	N0	M0	PSA X	Gleason X
IIB	T2c	N0	M0	PSA Any	Gleason Any
	T1–2	N0	M0	PSA ≥ 20	Gleason Any
	T1–2	N0	M0	PSA Any	Gleason ≥ 8
III	T3a–b	N0	M0	PSA Any	Gleason Any
IV	T4	N0	M0	PSA Any	Gleason Any
	T Any	N1	M0	PSA Any	Gleason Any
	T Any	N Any	M1	PSA Any	Gleason Any

Selecting patients for brachytherapy

When deciding whether or not to use brachytherapy, either alone or in combination with EBRT, it is useful to consider pretreatment urologic symptoms and prostate size. Acute urologic symptoms may also be more severe with brachytherapy, which makes it less ideal for patients with significant symptoms of benign prostatic hypertrophy (BPH) and those with large glands, the general cut-off being 50 g. Urinary symptoms are commonly rated using the AUA International Prostate Symptom Score (Table 114.3) [11], which is the same at the BPH Symptom Score but with a quality-of-life (QOL) question added. In the phase III trial, RTOG 0815, patients with an AUA score of greater than 15 are not candidates for brachytherapy, and the size cut-off is less than 60 g. Also, patients with a history of transurethral resection of the prostate (TURP) should not receive brachytherapy because of the increased risk of urethral toxicity, including incontinence [9]. Other factors that contribute to higher acute toxicity include a greater number of needles used to do the implant and the use of hormonal therapy [12].

Combination external beam radiation therapy and brachytherapy

There are no data to support either using EBRT alone or combination EBRT and brachytherapy in the treatment of intermediate-to-high-risk prostate cancer. In theory, the higher incidence of extracapsular extension and seminal vesicle invasion in intermediate-to-high-risk patients is more adequately covered by EBRT than brachytherapy, which is the rationale for avoiding brachytherapy alone in these patients. On the other hand, certain intermediate-risk patients are likely to be candidates for brachytherapy alone. In a retrospective review of 668 brachytherapy patients, there was no statistically significant difference in the 8-year actuarial biochemical relapse-free survival (BRFS) between low- and intermediate-risk patients, 98.4% and 98.2%, respectively [13]. These data suggest that most intermediate-risk patients have a low risk of micrometastatic disease in the pelvis. Even though the risk of extracapsular disease is higher in these patients, these areas may be adequately covered by an implant, since most extracapsular disease is located within 5 mm of the prostate capsule. In another series of combination therapy, where 63.4% of the intermediate-risk patients had 50% or more positive biopsy needle cores, there was an 80% 15-year BRFS [14]. These data suggest excellent long-term control with the combined approach. However, despite high control rates, the additional use of EBRT may be detrimental in terms of higher rates of morbidity. Therefore, additional pathologic factors, such as number or percentage of positive cores, may be helpful to determine whether or not a combination treatment should be used.

Postprostatectomy external beam radiotherapy

Adjuvant or salvage EBRT is used in the postprostatectomy setting. In general, the indications for postprostatectomy adjuvant radiation therapy include: positive margins, seminal vesicle invasion, extracapsular extension, and detectable PSA. The European Association for Research and Treatment of Cancer (EORTC) 22911 prospective phase III trial randomizing postprostatectomy patients with capsular penetration, positive margins,

Table 114.3 International Prostate Symptoms Score (IPSS).

	Not at all	Less than 1 time in 5	Less than half the time	About half the time	More than half the time	Almost always	
Over the past month, how often have you had a sensation of not emptying your bladder completely after you finished urinating?	0	1	2	4	4	5	
Over the past month, how often have you had to urinate again < 2 h after you finished urinating?	0	1	2	4	4	5	
Over the past month, how often have you found you stopped and started again several times when you urinated?	0	1	2	4	4	5	
Over the past month, how often have you had a weak stream?	0	1	2	4	4	5	
Over the past month, how often have you had to push or strain to begin urination?	0	1	2	4	4	5	
	None	1 time	2 times	3 times	4 times	5 or more times	
Over the past month, how many times did you most typically get up to urinate from the time you went to bed at night until the time you got up in the morning?	0	1	2	4	4	5	
Total symptom score ________________							
	Delighted						Terrible
If you were to spend the rest of your life with your urinary condition just the way it is now, how would you feel about that?	0	1	2	3	4	5	6

and/or seminal vesicle invasion to immediate radiation therapy of 60 Gy versus observation, showed an improvement in biochemical disease-free survival (BDFS) and disease progression, but no overall survival advantage. The 5-year progression-free survival was 74% for patients undergoing radiation therapy versus 52% undergoing observation [15]. The 5-year rate of grade 3 urinary toxicity was 2.6% in the observation arm and 4.2% in the treatment arm ($P = \cdot 0726$). Similar findings were reported in a multi-institutional randomized clinical trial comparing adjuvant radiation therapy of 60–64 Gy to observation with a median follow-up of 10.5 years. The metastasis-free survival was 64.5% in the treated group versus 56.9% in the observation group ($P = .06$) [16]. So, although there was improvement in PSA relapse and disease recurrence, there was no significant difference in survival. Without an improvement in survival, the controversy regarding whether or not to use adjuvant radiation therapy continues.

Results

Definition of biochemical failure

Results are generally reported by risk group and using BRFS since significant overall survival data may require decades to obtain. The definition of biochemical failure has recently been revised. The American Society for Therapeutic Radiology and Oncology (ASTRO) definition for biochemical failure requires three consecutive rises in PSA above the nadir [17]. Because of problems including backdating and inaccuracies with brachytherapy, the Phoenix definition of PSA nadir plus 2 ng/mL has been adopted [18]. With either definition, the dependence of outcome on dose and risk group is clear.

Multi-institutional long-term results

A total of 4839 patients were studied between 1986 and 1995 in a multi-institutional report of EBRT alone for stage T1b, T1c or T2 disease using doses of at least 60 Gy and no androgen deprivation therapy (ADT). With a median follow-up of 6.8 years, the 5- and 8-year PSA-DFS was 58% and 53%, respectively. For doses of 70 Gy or more, the results were 61% and 55%, respectively [19]. Data were complied for the 1325 patients treated during 1994 and 1995, comparing doses above and below 72 Gy for low-, intermediate- and high-risk groups. The overall 5-year PSA-DFS estimates for under 72 Gy versus 72 Gy and over were 63% versus 69%, respectively ($P = .046$); for patients with low-risk tumors, 75% versus 79%, respectively ($P = 0.359$); for patients with intermediate-risk tumors, 63% versus 72%, respectively ($P = 0.026$); and for patients with high-risk tumors, 38% versus 46%, respectively ($P = 0.126$) [20].

Combination therapy

Long-term BRFS rates for 223 patients with clinical stages T1–T3 prostate cancer treated from 1987 to 1993 with ^{125}I or ^{103}Pd brachytherapy after 45-Gy neoadjuvant EBRT without ADT were reported using different risk models. The results for a subset of intermediate-risk patients were described above. Overall, the 15-year BRFS for the entire treatment group was 74%. By risk group, the 15-year BRFSs were: low risk 85.8%, intermediate risk 80.3%, and high risk 67.8% ($P = .002$) [14]. In this study, only two rises in PSA instead of three were used to define biochemical failure. Also, the traditional four-field box technique was used. This early standard wide-field technique is the basis for improvement (see Treatment planning below).

Whole pelvis radiation therapy for high-risk disease

Whole pelvis radiation therapy is used for high-risk disease to treat microscopic involvement of the pelvic lymph nodes. The dose to the pelvis ranges from 4500 to 5040 cGy in standard fractionation. A higher dose to the prostate can be given as an external beam cone-down or with brachytherapy. RTOG 94-13 is a four-arm study randomizing patients who are at greater than 15% risk of pelvic node metastasis to whole pelvis or prostate-only radiation therapy and neoadjuvant or adjuvant ADT. At last analysis, it was not clear that there is an advantage to whole pelvis radiation over prostate-only radiation [21]. Although a whole pelvic field has been standard for many trials treating high-risk prostate cancer, two of which are described below, further research will be needed to answer the question definitively. Since treatment to the whole pelvis increases the morbidity of treatment, the answer is of the utmost importance.

Androgen deprivation for high-risk disease

Neoadjuvant and concurrent ADT is generally recommended. RTOG 85-31 demonstrated a significant improvement in disease progression and absolute survival at 10 years with the addition of ADT to standard EBRT whole pelvis plus cone-down to total doses of between 65 and 70 Gy [22]. Between 1987 and 1992, 977 patients were randomized to goserelin with radiation therapy or at time of relapse. The 10-year survival rate was 49% in the treatment arm versus 39% in the delayed arm ($P = .002$). The 10-year local failure rate was 23% in the treatment arm versus 38% in the delayed arm ($P < .0001$). Similarly, a randomized phase III trial of the EORTC showed a significant DFS and overall survival in favor of hormone therapy. Between the years 1987 and 1995, 415 patients were randomized to whole pelvis radiation therapy of 50 Gy plus a 20-Gy prostate cone-down with or without goserelin and cyproterone acetate. At median follow-up of 65.7 months, there was a significantly improved 5-year DFS of 74% versus 40% with the use of hormonal therapy ($P = .0001$). The 5-year overall survival was 78% in the hormone group versus 78% in the radiation therapy alone group ($P = 0.0002$) [23].

Toxicity profile

Anatomic considerations

By virtue of its anatomic location, anterior to the rectum and posteroinferior to the bladder, treatment to the prostate results in mainly acute urinary and rectal side effects. The urethra, running right through the gland, can hardly be avoided. Neurovascular bundles responsible for erectile function run alongside the right and left posterolateral apical aspects of the gland (Figure 114.1). As a result of their location, these structures receive a relatively high dose of radiation therapy and sustain most of the collateral damage from treatment. Imaging plays a primary role in locating these structures to assist in minimizing the planned dose and also maintaining precision of treatment delivery. The ultimate goal is to improve the therapeutic margin by increasing dose to the prostate, while reducing dose particularly to the bladder and rectum.

Grading toxic events

The EORTC/RTOG criteria of acute and chronic radiation morbidity are provided for all different clinical systems. Acute morbidities for lower gastrointestinal and genitourinary side effects, often cited for prostate cancer treatment, are listed in Table 114.4. The criteria

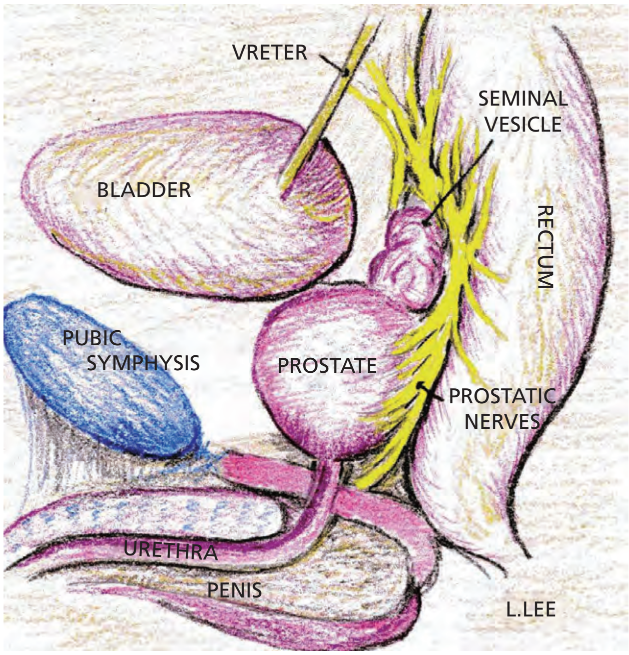

Figure 114.1 Prostate *in situ*.

Table 114.4 Radiation Therapy Oncology Group (RTOG) acute radiation morbidity scoring criteria.

Score	0	1	2	3	4
Lower gastrointestinal	No change	Increased frequency or change in quality of bowel habits not requiring medication/rectal discomfort not requiring analgesics	Diarrhea requiring parasympatholytic drugs/mucus discharge not necessitating sanitary pads/ rectal or abdominal pain requiring analgesics	Diarrhea requiring parenteral support/ severe mucus or blood discharge necessitating sanitary pads/ abdominal distention (distended bowel loops on radiograph)	Acute or subacute obstruction, fistula or perforation; GI bleeding requiring transfusion; abdominal pain or tenesmus requiring tube decompression or bowel diversion
Genitourinary	No change	Frequency of urination or nocturia twice pretreatment Habit/dysuria, urgency not requiring medication	Frequency of urination that is less frequent than every hour Dysuria, urgency, bladder spasm requiring local anesthetic (e.g. phenazopyridine)	Frequency with urgency and nocturia hourly or more frequently/dysuria, pelvic pain or bladder spasm requiring regular frequent narcotic/gross hematuria with/ without clot passage	Hematuria requiring trans-fusion/acute bladder obstruction not secondary to clot passage, ulceration or necrosis

Table 114.5 European Association for Research and Treatment of Cancer (EORTC)/Radiation Therapy Oncology Group (RTOG) criteria of late effects.

Score	0	1	2	3	4
Small/large intestine	None	Mild diarrhea; mild cramping; bowel movements 5 times daily; slight rectal discharge or bleeding	Moderate diarrhea and colic; bowel movement >5 times daily; excessive rectal mucus or intermittent bleeding	Obstruction or bleeding requiring surgery	Necrosis/ perforation fistula
Bladder	None	Slight epithelial atrophy; minor telangiectasia (microscopic hematuria)	Moderate frequency; generalized telangiectasia; intermittent macroscopic hematuria	Severe frequency and dysuria; severe telangiectasia; frequent hematuria; reduction in bladder capacity (<150 mL)	Necrosis/ contracted bladder capacity (<100 mL), severe hemorrhagic cystitis

Table 114.6 Common Terminology Criteria for Adverse Events (CTCAE) Version 4.0 grading system.

Grade refers to the severity of the adverse event:	
Grade 1	Mild; asymptomatic or mild symptoms; clinical or diagnostic observations only; intervention not indicated
Grade 2	Moderate; minimal, local or noninvasive intervention indicated; limiting age-appropriate instrumental activities of daily living (ADL)*
Grade 3	Severe or medically significant but not immediately life-threatening; hospitalization or prolongation of hospitalization indicated; disabling; limiting self-care ADL**
Grade 4	Life-threatening consequences; urgent intervention indicated
Grade 5	Death related to adverse event

*Instrumental ADL refer to preparing meals, shopping for groceries or clothes, using the telephone, managing money, etc.

**Self-care ADL refer to bathing, dressing and undressing, feeding self, using the toilet, taking medications, and not bedridden.

Table 114.7 Acute toxicity with intensity-modulated radiation therapy (IMRT) to 81–86.4 Gy (n = 772).

Toxicity	Grade	Gastrointestinal	Genitourinary
	0	568 (74%)	258 (33%)
	1	169 (22%)	296 (38%)
	2	35 (4%)	217 (28%)
	3	0	1

Table 114.8 Late toxicity intensity-modulated radiation therapy (IMRT) to 81–86.4 Gy (n = 772).

Toxicity	Grade	Gastrointestinal	Genitourinary
	0	688 (89%)	570 (74%)
	1	69 (9%)	121 (16%)
	2	11 (1.5%)	76 (9.5%)
	3	4 (0.5%)	5 (0.5%)

for late effects are determined after the 90th day from the commencement of therapy and are listed in Table 114.5 [24]. Common Terminology Criteria for Adverse Events (CTCAE) provide similar information and are also frequently used. Version 4.0, released in May 2009 and updated in September 2009, includes a range of grades for various toxicities. The grading system ranges from 1 to 5: asymptomatic, symptomatic, severely altered function, life-threatening consequences, and death, respectively (Table 114.6). Rectal toxicities include rectal fistula, hemorrhage, mucositis, necrosis, obstruction, pain, perforation, and ulcer. Urinary toxicities include urinary fistula, frequency, incontinence, retention, tract obstruction, tract pain, urgency, cystitis and hematuria. Other adverse events that may apply to prostate cancer treatment include ejaculatory disorder and erectile dysfunction.

Morbidity data

Current NCCN practice guidelines recommend doses of 75.6–79 Gy for low-risk disease and 78–80+ Gy for intermediate- to high-risk disease. Acute toxicities were reported for 772 patients undergoing IMRT to 81–86.4 Gy between the years 1996 and 2001 (Table 114.7). These doses are at the upper end of the recommended dose spectrum and they resulted in relatively low morbidity. Most patients developed grade 0–1 acute toxicity and there was one grade 3 urinary complication of obstruction. Late toxicity is shown in Table 114.8. With a median follow-up of 24 months, most patients had no residual gastrointestinal symptoms (89%) and many had no urinary symptoms (74%). At a median of 9 months, 1.5% had developed grade 2 rectal bleeding and 0.5% grade 3 bleeding requiring transfusion or laser cauterization. At a median of 6 months, 9.5% had developed grade 2 chronic urethritis requiring medication for symptom control and 0.5% grade 3 urethral stricture requiring dilation. Among the 540 patients who were potent prior to treatment, 52% maintained erectile function at 2 years post treatment [25]. Longer follow-up will be important for documenting chronic toxicity at these doses. For patients treated between 1988 and 2000 to 66–81Gy using either three-dimensional (3D)-conformal techniques or IMRT, CTCAE criteria were reported for a median 10-year follow-up. The 10-year actuarial incidence of grade 2 or greater gastrointestinal toxicity was 9% and of genitourinary toxicity was 15%. The use of IMRT reduced the incidence of proctitis from 13% to 5% ($P > .001$) [26].

Quality of life

A prospective study examining acute and late toxicity and QOL up to 18 months after IMRT to 76Gy showed similar findings to the morbidity data reported above and acceptable QOL. Acute urinary grade 2 and 3 toxicity was 38% and 2%, respectively. Acute bowel grade 2 and 3 toxicity was 13% and 0%, respectively. Temporary detriment in QOL, mainly due to urinary symptoms, reverted back to initial scores by 18 months [27]. A QOL comparison of treatment with 3D-conformal therapy to 70Gy versus IMRT to 76Gy using fiducial markers to verify position, showed no detriment for the higher dose using IMRT at 1 and 6 months after treatment. There was actually an improvement in pain and urinary symptoms within the first month [28]. These techniques are detailed under Treatment planning (see below).

Secondary malignancies

Secondary malignancies are a rare but dreaded complication of therapeutic ionizing radiation. A secondary malignancy is characterized by occurrence within the prior radiation portal and usually has a latency of several years or longer, especially for solid tumors. The potential for developing secondary malignancies is generally greater for a younger patient because of the likelihood of longer survival compared to an older patient. SEER data comparing over 50 000 patients treated with radiotherapy and over 70 000 patients treated with surgery for prostate cancer, showed a small but statistically increased risk of developing tumors of the bladder, rectum, and lung, and also sarcoma. There was an increased relative risk of 15% for patients surviving 5 years or more, and 34% for patient surviving 10 years or more. The absolute risk of developing a secondary malignancy from radiation therapy was 1 in 290 patients, increasing to 1 in 70 for those surviving 10 years or more [29]. These data are consistent with other reports [30–33]. When brachytherapy is examined separately, the risk does not appear to be as for EBRT [31, 32]. Therefore, if otherwise reasonable, brachytherapy may be a better choice for the younger patient.

Treatment planning

Simulation details

Treatment planning begins with a simulation. The patient is positioned for the treatment and immobilization devices are used to ensure that the patient's position is reproducible on a daily basis. These may include a thermoplastic mold stretched over the pelvis and secured to the table. Various techniques to identify certain structures, such as a Foley catheter and rectal catheter, or contrast dye may be useful to define the bladder and rectal margins. Comfort measures such as a hand ring or wedge under the knees may be offered. Kilovoltage (kV) X-rays, generally a set of orthogonal films overlain with a grid, are obtained at the time of simulation and serve as the baseline for future set-up verification. Tattoos are placed on the skin at the center of the anterior and two lateral fields in order to "triangulate" the isocenter. In the traditional four-field box technique, treatment was from anterior, posterior, right lateral, and left lateral directions (Figure 114.2). Field borders were designated on the films and generally corresponded to bone landmarks, e.g. the inferior border was set at the bottom of the ischial tuberosities. Cerrobend, a lead alloy, was constructed in blocks as needed, e.g. to shield the posterior rectum based on the configuration of the rectal contrast on the film. Currently, ball bearings are placed on the tattoos and a CT scan of the pelvis is obtained instead of X-ray films. Digitally reconstructed radiographs (DRRs) are generated from the CT information (Figure 114.3).

Portal imaging

The traditional method of checking a patient's set-up during treatment is weekly megavoltage (MV) portal imaging. This involves obtaining a set of orthogonal films, using the skin tattoos to locate the isocenter. These images utilize the MV energy of the treatment itself, which provides films of poor quality, but which are generally suitable for visualizing the bone anatomy. When overlain with a grid, these images can be compared with the initial set of therapeutic quality

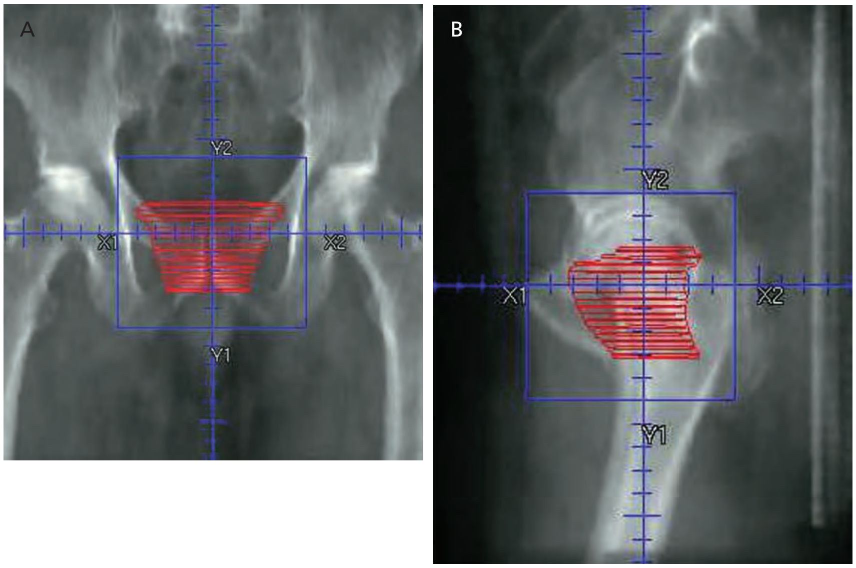

Figure 114.2 (A, B) Examples of anterior and lateral beam appearance from four-field box technique.

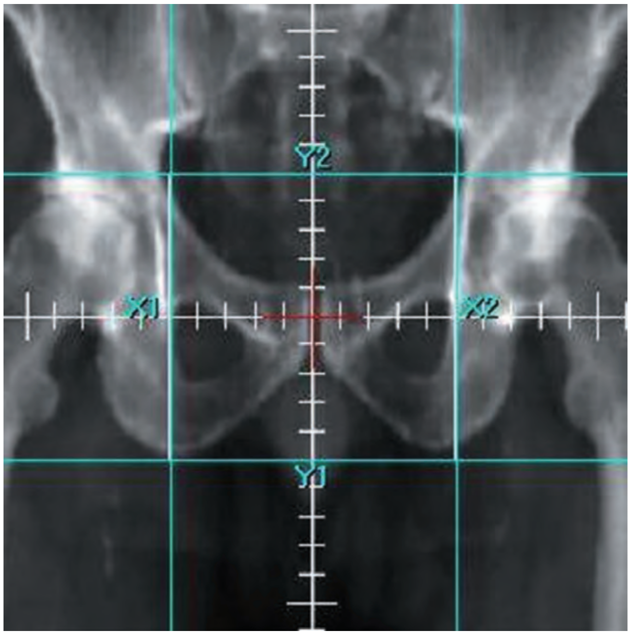

Figure 114.3 Digitally reconstructed radiograph.

simulation films or DRRs obtained at the beginning of treatment to verify the patient's position (Figure 114.4). Weekly MV portal images are the primary form of verification and continue to be used in standard practice.

Target volume delineation

The CT images are reviewed using treatment planning software, many of which are commercially available. The area of interest is outlined on each slice to generate a target volume. Target volumes generally include a gross tumor volume (GTV), a clinical target volume (CTV) which includes microscopic disease, and a planning target volume (PTV), which includes the CTV with a margin for error. For the treatment of prostate cancer, the CTV rather than the GTV is usually outlined. This includes the entire prostate gland since CT does not give enough detail to outline gross tumor. Moreover, multifocal disease is common. While the PTV usually includes the proximal aspect of the seminal vesicles, more advanced disease may warrant full coverage. The PTV is often represented by a volume that is generated by expanding the prostate volume by 1 cm in all directions. Differential margins are often used. For example, since the rectum is adjacent to the prostate with little or no room in between, this margin is often smaller, i.e. 5–6 mm. In a dose escalation study comparing 70 Gy to 78 Gy, anterior and inferior margins of 1.25–1.5 cm and posterior and superior margins of 0.75–1.0 cm were used [34]. As doses increase and treatment becomes more conformal, margins will likely shrink.

3D-conformal radiation therapy

3D-conformal radiation therapy improves upon the traditional four-field box technique (see above). CT information obtained at the time of simulation allows an unlimited variety of beams to be chosen to optimize treatment delivery. Since an increasing number of beams adds to the treatment time and patient discomfort, a typical plan might use five to seven beam angles. In a typical prostate treatment plan, beams target the pros-

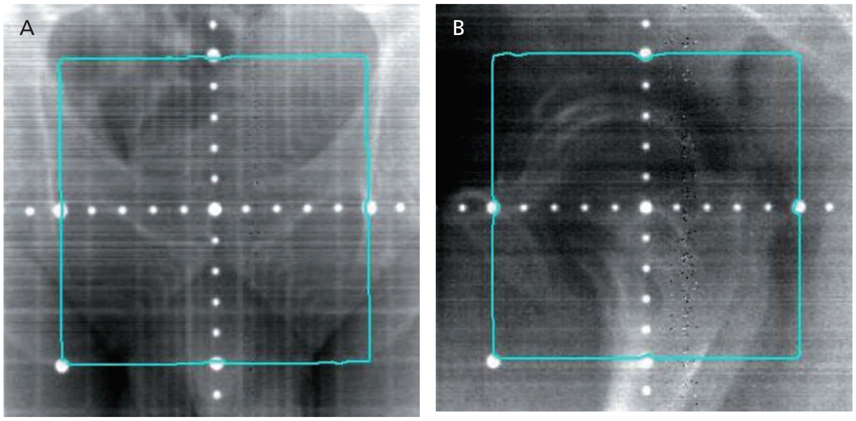

Figure 114.4 (A, B) Orthogonal portal images for prostate treatment verification.

tate while avoiding the bladder, rectum, and femoral heads (Figure 114.5). Differential weighting or adjusting the fractional dose per beam fine tunes the coverage of the target volume. Various techniques for collimation can be employed, including the use of cerrobend blocks that closely conform to the PTV (Figure 114.6). Wedges placed in front of the beam provide a dose gradient across the field in any one of four directions. These advances have paved the way for dose escalation and reduced margins.

Dose escalation

A dose escalation study randomized 305 patients from 1992 to 1998 with T1–T3 disease to 70 Gy in 35 fractions via a four-field box technique or 78 Gy in 39 fractions using a six-field 3D-conformal technique [34]. Freedom from biochemical or clinical failure was significant and increased with time in favor of the higher dose: 85% versus 78% at 5 years, 78% versus 59% at 8 years, and 73% versus 50% at 10 yrs ($P = .004$). The 10-year incidence of Radiation Therapy Oncology Group (RTOG) grade 3 gastrointestinal toxicity was significantly higher with the 78 Gy dose (26% vs 13%). However, genitourinary toxicities were not significantly different between the doses, and there were no grade 4 or higher toxicities. A meta-analysis of randomized controlled trials suggested that high dose was beneficial for all risk groups compared to conventional dose treatments [35]. Furthermore, a meta-regression analysis predicted close to 100% biochemical control for doses around 90 Gy, especially for the low-risk group. Significantly higher grade 2 or greater gastrointestinal toxicity was also seen, but there was no significant difference is genitourinary toxicity [35]. It is notable that this and other dose escalation studies are unable to show a survival advantage because of the prolonged natural history of prostate cancer, with patients often dying from other causes. The issue is raised whether the improvement in biochemical control is worth the added toxicity, albeit mild.

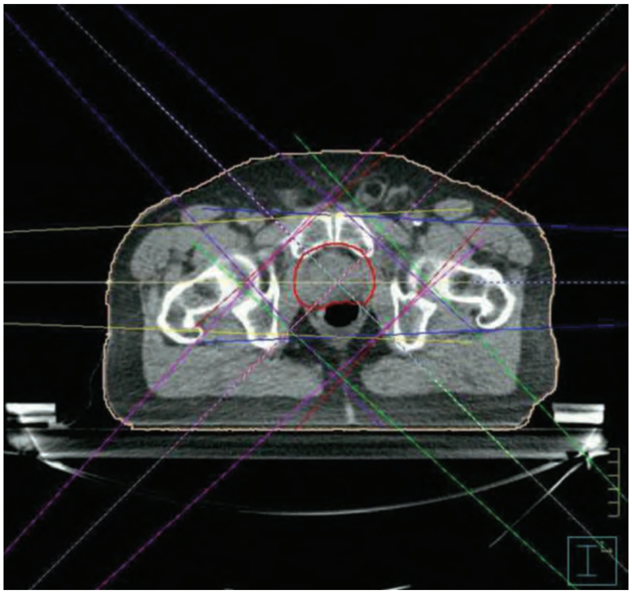

Figure 114.5 Axial slice of six-field 3D-conformal plan.

Rectal dose–volume relationships

Rectal dose–volume relationships have been studied in detail. The percentage of rectal volume receiving 70 Gy (V70) predicts for chronic toxicity. In one study the rectal doses of 331 patients undergoing 3D-conformal radiation therapy to 75.6 Gy were analyzed. With a median follow-up of 1.6 years, a V70 of less than 25%, 25–40%, and greater than 40% resulted in grade 2 or greater toxicity rates of 9%, 18%, and 25% respectively [36]. A similar analysis was done on 163 patients treated with 3D-conformal techniques to 74–78 Gy and a median follow-up of 62 months. The 6-year rate of rectal

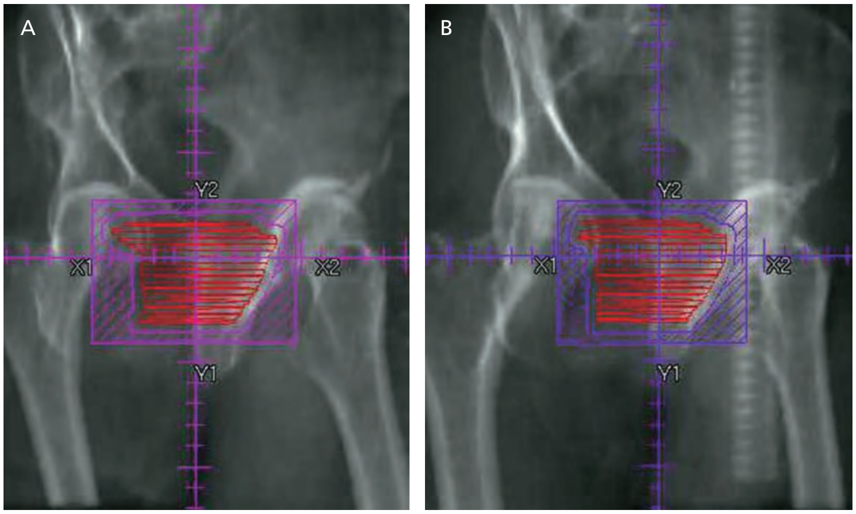

Figure 114.6 (A, B) Examples of two oblique fields of a six-field plan with blocking around planning target volume (PTV) shown in red.

complications of grade 2 or higher was 54% versus 15% for V70 of greater than 26.2% versus 26.2% or smaller, respectively [37]. Further analysis showed that even at lower doses, high volume resulted in increased toxicity. There was a 50% or higher incidence of grade 2 toxicity or worse within 2 years if 80% or more of the rectal wall was exposed to 32 Gy [38]. These data allowed limits to be set for future treatment planning. These limits are generally achievable with IMRT.

Intensity-modulated radiation therapy

IMRT expands on the simple wedges used to provide a gradual dose gradient across a field. This technique utilizes a series of miniature sliding doors, called mutlileaf collimators (MLCs), which differentially attenuate the radiation beam. Since the MLCs can remain open or closed in innumerable positions, the ability to collimate the radiation beam is vastly improved.

Treatment delivery

Set-up uncertainty and rectal variability

Traditional methods of orthogonal portal images and skin tattoos lead to margin uncertainties as large as 1–2 cm [39]. Positioning based on bone anatomy is clearly limited in its ability to reproduce organ position. This could be addressed by increasing the margins, but in the area of the prostate, increased margins lead to increased complications [40]. A study of weekly CT scans on six patients showed significant interfraction target position variability. Estimates of PTV margins in the anteroposterior (AP), craniocaudal (CC), and mediolateral (ML) directions to cover the CTV with 95% certainty were: 12.4 mm, 10.3 mm, and 5.6 mm, respectively, for the prostate, and 13.8 mm, 8.6 mm, and 3.9 mm, respectively, for the seminal vesicles [41]. Rectal variability is reproducible and appears to be responsible for most of the variation [42, 43]. For example, the prostate may be located posteriorly if a patient has diarrhea and less rectal filling. On the other hand, the prostate may be located more anteriorly if the patient has proctitis or tends to tense the pelvic muscles during treatment. Therefore, corrections are not universal and ideally should be tailored to the individual.

Bladder volume

The bladder appears to contribute less to target position variability than the rectum [41]. An empty bladder is more reproducible than a full bladder, but allows a larger volume of bladder to be exposed to the high-dose area. Conformal treatments such as IMRT can reduce bladder volume significantly. Patients can also be treated with a full bladder, but this state tends to be less reproducible with variable bladder volumes from day to day. In addition, the patient may tense the pelvic muscles to postpone urination, which may lead to changes in prostate position [39]. However, if the patient can train himself to have a consistently full bladder for treatment each day, the major advantage is that a significantly smaller volume of bladder will be in the high-dose area.

Intrafraction error

Intrafraction error, which occurs during a single treatment, dramatically increases the complexity of target motion. While breathing can result in predictable sinusoidal patterns, motion in the region of the prostate has been described as "slow drift" or "sudden transient" due to acute changes in colonic content [44]. A study of 21 patients was conducted where a CT was done before and after treatments to determine the intrafraction error. Prostate drifts of greater than 5 mm were found in 12% of all fractions, and a margin of 6 mm was determined to compensate for these changes [45]. These unpredictable movements suggest a benefit to localization and tracking the prostate during treatment. Image-guided radiation therapy includes various methods to achieve these goals.

Methods for image-guided radiation therapy

Placement of fiducials

Fiducial markers are usually made out of metal and vary in size and configuration. Commonly used fiducials are made of gold and can be shaped like pellets or coils. For the prostate, gold fiducials usually measure less than 1 mm in diameter and a few millimeters in length. A textured surface, as with the coils, can reduce migration. Preparation for the procedure includes an enema the night before and on the morning of the procedure. Antibiotics are prescribed prophylactically to prevent infection. For example, ciprofloxacin 500 mg may be taken twice a day for 3 days. When the implantation site is identified on rectal ultrasound, approximately 1–3 mL of lidocaine 1% is injected for local anesthesia. The fiducials are placed into an introducer needle and then placed into the site with a stylet. Toxicity is generally minor, including bleeding such as hematuria, hematospermia, and hematochezia; generally lasting for a day or two. There may be mild rectal discomfort, which is usually improved with acetaminophen. Sepsis is also a possibility, but rare.

On-board imaging

A logical advance in weekly portal imaging is to use therapeutic quality X-rays so that the images are closer in quality to the simulation films. A kV X-ray tube mounted opposite an image detector is conveniently added to any existing linear accelerator, and is otherwise known as on-board imaging (OBI). The high resolution allows for better visualization of skeletal anatomy and also of fiducials implanted in soft tissues. An additional benefit of this system is a significantly lower dose of radiation, about 0.01–0.1 cGy/film; MV imaging gives an estimated 4–16 cGy/orthogonal pair [46]. The lower dose given with kV images makes daily imaging for localization more reasonable. In order to make the process of daily filming time efficient, an electronic portal imaging device (EPID) is often used rather than traditional film processing. In addition, a kV fluoroscopy unit can be used to localize fiducials at the start of treatment, and then can provide realtime tracking of the fiducials during treatment [47]. The treatment may be held if the fiducials move out of a predetermined volumetric range, then restarted when the fiducials move back into range. This process is referred to as gating and can be used with other realtime tracking techniques.

CT-based verification

Since CT-based planning has become the norm for 3D-conformal and IMRT planning, using CT for verification is a logical advance. CT provides soft tissue detail and a 3D aspect to verification, a clear improvement upon the traditional 2D orthogonal films. CT-based verification may utilize either kV or MV energies. The pros and cons of these are similar to those for the respective X-ray films. The images can also be obtained using either a helical beam or a large field cone beam [48]. The helical beam opposite the detector makes multiple rotations around the patient in order to obtain the necessary data to construct the images. The large field cone beam is opposite a flat panel detector, which can acquire the data in a single rotation [49].

Cone-beam MV CT utilizes the treatment beam itself to provide the images. The system is easy to implement since it only requires an EPID mounted onto an existing machine. The wide field beam is subject to divergence and scatter, which reduces the quality of the images. The dose to the patient is relatively high, approximately 5–15 cGy/scan [50]. Helical MV CT (TomoTherapy, Madison, WI, USA) is a combined CT scanner and linear accelerator that utilizes the continuous motion of the gantry and couch of a diagnostic helical CT scanner to provide both imaging and treatment. It exposes the patient to less radiation, about 1–2 cGy [48], but it may take longer to acquire the necessary images since multiple rotations around the patient are needed to complete the process. As a result, the images are more likely to show motion artifact due to respiration. Although poor relative to kV images, the image quality of MV CT is sufficient for positioning corrections based on skeletal anatomy. A primary advantage to using MV CT is the reduced artifact from orthopedic hardware [49]. This can be useful for patients with a hip prosthesis. It is particularly useful for visualizing fiducials because of the lack of a star-like artifact that can be present in kV images. Compared to kV imaging, the disadvantages include poorer anatomic image quality and increased dose to the patient.

A kV CT system provides excellent resolution since the CT is of diagnostic quality and is actively under investigation for advances in image adaptive techniques. For example, head and neck tumors have the potential to change rapidly in size during treatment and are often surrounded by multiple soft tissue organs of interest, such as the parotid glands and spinal cord. The CT information used for verification can be used not only to re-align the patient, but also to replan the treatment if there are major anatomic differences. The system may be more difficult to implement than MV CT since it requires a CT unit separate from the linear accelerator. Moreover, the patient must remain immobilized in the treatment position for both scans. With a 180° couch rotation, the patient can be moved from the linear accelerator to the mobile CT unit, which then can be moved into position for the scan [48].

kV cone-beam CT can offer several advantages, including superior imaging as well as realtime tracking ability from the fluoroscopic capability. A kV unit is mounted 90° from the gantry of the linear accelerator and opposite an X-ray detector. Sub-millimeter accuracy has been reported with this system. Since the image registration requires a full rotation over a period of about 1 min, the system can still be subject to inaccuracies from breathing and other motions [48]. The system is well-suited for intracranial radiosurgery but may require gating techniques for lung tumors.

Ultrasound verification

The B mode Acquisition and Targeting System (BATS) is a portable ultrasound localization device. CT data from the simulation are transferred to the system. Ultrasound imaging is performed prior to treatment and matched to the original CT images. If the images differ, the system will then produce the necessary couch shifts in order to realign the patient to match the ultrasound realtime images [51]. Despite the ease of implementation, accuracy may not be as high as with CT verification techniques due to the lower image quality and the potential for the probe itself to move the prostate [52, 53]. Therefore, the technique is more dependent on user skill and interpretation of images. One major disadvantage is the lack of tracking ability.

Electromagnetic field tracking

A major advantage to electromagnetic field tracking is the lack of additional ionizing radiation. The Calypso 4D Localization System (Calypso Medical Technologies, Seattle, WA, USA) requires the implantation of beacon transponders, which carries the same risks as implantation of fiducials. Although anatomic images are not produced, the corrections are objective and do not require user skill and interpretation.

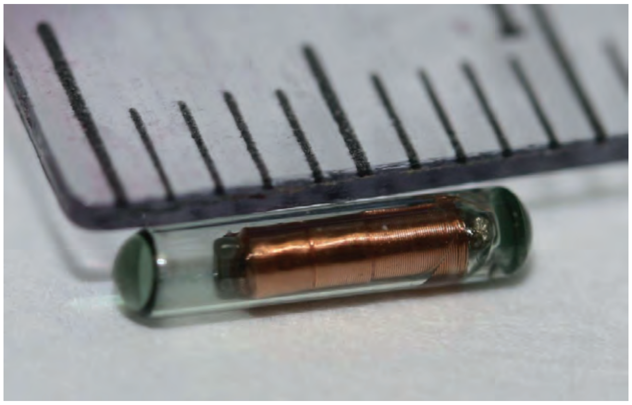

Figure 114.7 Close up of Calypso (Calypso Medical Technologies, Seattle, WA, USA) beacon transponder next to millimeter ruler demonstrating internal electromagnetic coils.

Transponder placement

The beacon transponder contains a miniature electrical circuit sealed in a glass capsule, measuring 1.85 mm in diameter and 8 mm in length (Figure 114.7). Like fiducials, transponders are implanted into the left lobe, right lobe, and apex of the prostate gland via 14G introducer needles. Transponders may migrate soon after the procedure. The mean of the standard deviation of inter-transponder distance variation measured at 4 days after implantation was 1.3 mm and 0.8 mm at 14 days after implantation [54, 55]. This compares favorably to gold seed markers, for which the mean of the standard deviation of intermarker distance variation measured throughout the course of treatment was 1.0 mm [56]. Like fiducials, beacons may become lost due to implantation into the urethra or into the venous plexus going to the seminal vesicles, but in the majority of cases they are quite stable. Another potential route for loss of a transponder located between the prostate and rectum could be through the rectal wall. In 60 patients, one study reported loss of one beacon via the urethra and one to the venous plexus [54]. The mean standard deviation of the intertransponder distances over a period from 4 days post implant through the last radiation fraction was 0.8 mm. There was no significant difference in the stability of the transponders placed at the base versus the apex [57]. Overall, these data demonstrate significant stability of the geometry of implanted transponders throughout an entire course of EBRT, which is typically 8–9 weeks.

Simulation procedure

The patient then returns for simulation about 1–2 weeks later. Patients are supine for the simulation, and CT scan slices of 1–1.5 mm of the pelvis are obtained. Previous work has shown that transponder locations are known to within 0.7 mm using thin-slice CT [58]. Immobilization devices are generally minimal. The treatment planning CT is done as usual and the isocenter is placed in the middle of the beacons. Then the coordinates of the beacons in reference to the isocenter are entered into the Calypso software.

Localization

When the patient is ready to be treated, the beacon transponders are located, which includes identifying their positions in 3D space relative to each other. An electromagnetic array, containing source and receiver coils, is placed over the patient. The source coils emit an electromagnetic signal that excites the beacon transponders. The signal is then turned off, and the receiver coils then detect the signal emitted from the transponders. Each transponder has a unique resonant frequency so that each one can be distinguished from the others. A best geometric fit is determined to match the coordinates from the simulation data entered previously into the system. This correction is translated into couch movements, which will move the patient to the corrected position. When a patient is set-up with skin tattoos and verified with the Calypso system, most of the corrections are within 1.5 cm, but approximately 10% are greater than 1.5 cm, demonstrating the value of localization. Compared with the kV X-ray localization methods, the accuracy of the Calypso system is less than 1.5 mm.

Tracking

For tracking, position updates are obtained at 10-Hz frequency and the differences between the actual isocenter and the calculated isocenter are displayed graphically, providing the fourth dimension of time (Figure 114.8). If the movement is outside a set threshold of, for example, 3 mm, then the operator has the option of stopping the treatment until the target is back in alignment, or performing a couch correction if needed. Most of the lateral shifts are within 5 mm but about 8% exceed 1 cm. Large lateral shifts tend to be more common in large

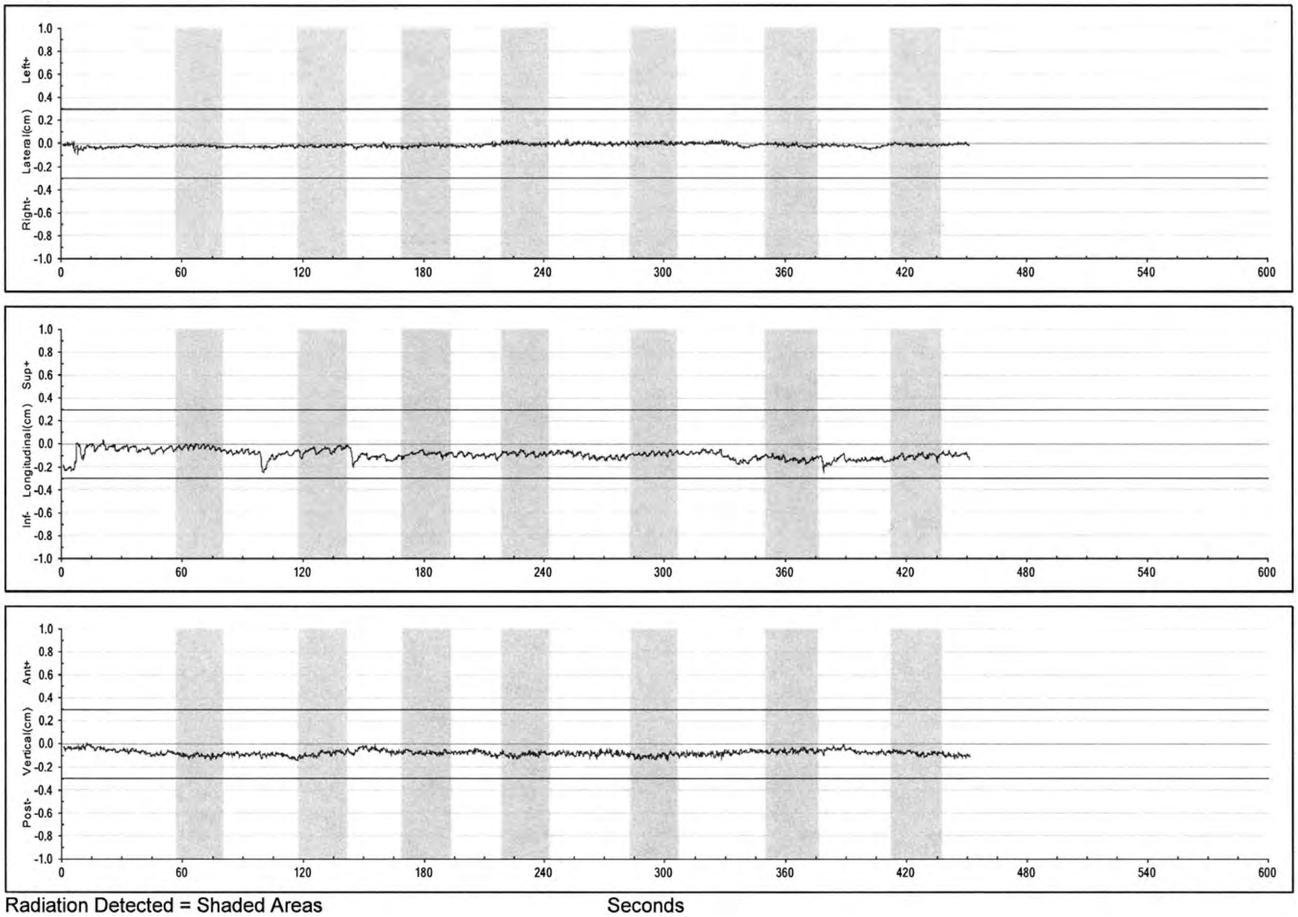

Figure 114.8 Calypso session report showing patient remaining within set threshold; gray areas represent when the radiation is turned on.

patients. Superoinferior shifts tend to be within 5 mm, suggesting relatively limited movement in these directions. Anteroposterior shifts, depending on rectal contents, are most common and are usually within 1.5 cm. Tracking data show that motion of more than 5 mm for longer than 30 s occurs during 15% of the fractions [57]. With the exception of a slow posterior shift associated with relaxation, many of these movements are unpredictable and pose a challenging problem for future improvements and developments.

Conclusions

Image-guided radiation therapy offers a wide range of techniques, which allow an improved therapeutic ratio in the treatment of prostate cancer by increasing the dose to the tumor for better tumor control, while reducing the dose to adjacent critical organs for lower morbidity. This goal drives much of the research performed in the field of radiation medicine and promises to improve outcomes and QOL for patients.

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CHAPTER 115

High-Intensity Focused Ultrasound of the Prostate

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Introduction

For more than 70 years it has been well known that tissue can be destroyed from a distance by high-intensity focused ultrasound (HIFU). However, clinical implementation of this technology was delayed due to the lack of reliable control. Special software, transrectal ultrasound (TRUS), and magnetic resonance imaging (MRI) now allow for realtime control and monitoring of HIFU treatment. Therefore, treatment with HIFU can now be extended to different surgical areas as an extracorporeal method, which allows the noninvasive destruction and removal of tissue without a formal surgical procedure. Increased experience and literature on HIFU has led to increasing acceptance and validation of transrectal HIFU treatment of prostate cancer internationally. Long-term results have been published, but as yet these do not extend to 10 years [1, 2].

In addition to the clinical application of HIFU for prostate cancer, there are currently several clinical trials ongoing for the treatment of benign and malignant tumors, such as kidney, breast, liver, thyroid, brain, uterine fibroids, and glaucoma.

Principle of high-intensity focused ultrasound

HIFU for local tissue destruction was first used in 1942 [3]. High-energy ultrasound parabolically focused on tissue leads to mechanical alteration of cells and changes in biologic structures (Figure 115.1). Three different mechanisms can be observed: mechanical, cavitation, and thermal effects.

Mechanically, the negative pressure of the ultrasound wave forms cavitation bubbles within the tissue. The cells increase in size to the point at which resonance is achieved. High pressure of about 20 000–30 000 bars develops when the bubbles suddenly collapse, causing instant mechanical cell death.

The thermal effect is caused by the absorption of ultrasonic energy in tissue. The temperature increase in tissue depends on the absorption coefficient of the tissue, and the size, shape, and temperature sensitivity of the heated area. The biologic changes caused by the heating depend on the temperature level and duration of exposure. A "thermal dose," which exceeds a certain threshold, causes irreversible tissue damage in the form of coagulation. For thermal doses below the threshold, the effect of temperature depends upon the tissue sensitivity [4].

During HIFU, the ultrasound generates a very high intensity in the focal area, while the surrounding tissue is only slightly charged. Focused ultrasound waves causing high temperature within a few seconds (70–c. 100° C) destroy the tissue in a circumscribed area, while surrounding areas remain unharmed. The tissue volume that is destroyed by a single ultrasonic beam is called the "primary" lesion. In order to create lesions in larger areas, multiple lesions have to be added to the primary lesion (Figure 115.2). This can be achieved by mechanically moving the energy source or in the case of an existing "phased array," electronically altering the focal point [4–6].

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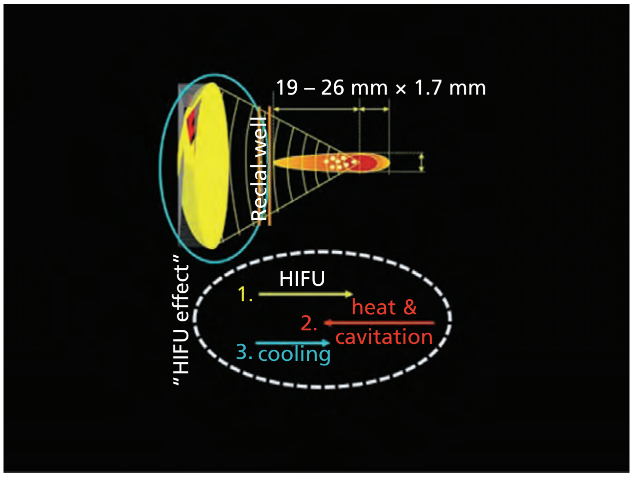


Figure 115.1 Physical principle of high-intensity focused ultrasound (HIFU).

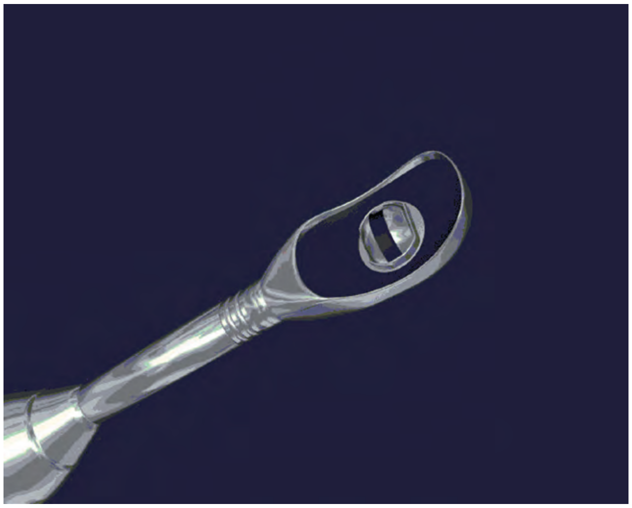


Figure 115.3 Applicator.

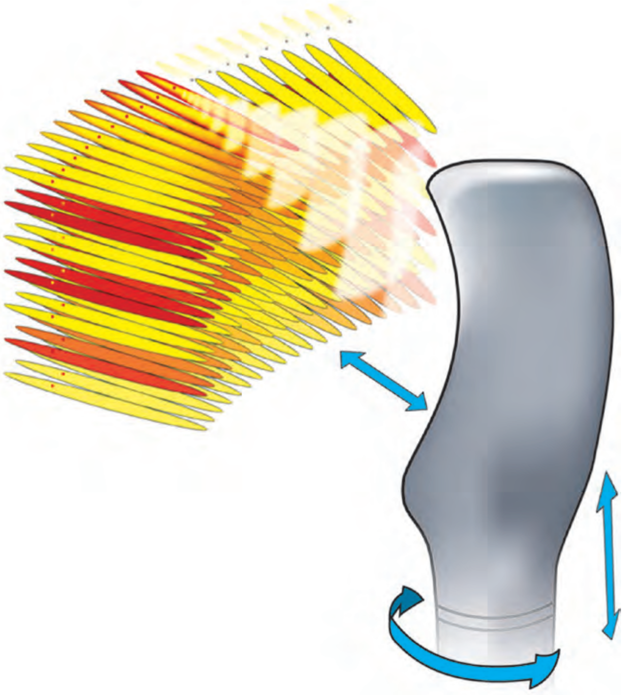


Figure 115.2 Multiple lesion distribution.

Technology

Several parameters are essential to the development of an HIFU system for a specific application. The most difficult technical decisions concern the selection and design of the piezoelectric energy converter, the parameters of ultrasound treatment (megaHertz, Watts), and the imaging system and localization during treatment (TRUS, MRI).

The therapeutic ultrasonic energy transducer is characterized mainly by the operating frequency and the geometric and physical dimensions (Figure 115.3). Modern piezoelectric systems can be operated with energy density, reproducibility, and long-term stability sufficient to meet the requirements of the therapy. These systems also allow the production of geometric shapes to align them to different anatomic requirements [7].

Current standard urologic applications use HIFU transducers with a fixed focal point that can be moved mechanically to treat large tissue volumes (Figure 115.4). Future applications, however, may use "phased-array transducers," that the focal point can be moved without changing the position of the applicator [8, 9].

The main parameters of the ultrasound treatment are the acoustic intensity, duration of application, interval of the pulses, lateral distance between elementary lesions, as well as the longitudinal displacement of the energy source when treating multiple lesions. To find the ultrasound parameters that are required for treatment of the prostate, *in vitro* and *in vivo* experiments have been performed, as well as computer simulations [10–12].

MRI is the technique of choice to assess the effectiveness of HIFU treatment and to perform realtime temperature measurements. The extent of necrosis on gadolinium-enriched T1-weighted images appears as a clearly visible hypodense zone [13]. MRI is used in extracorporeal HIFU treatments for localization and monitoring of effectiveness [13, 14], and allows for the measurement of temperature changes during HIFU treatment [13]. A few studies have used magnetic resonance elastography (MRE) to investigate the effects of temperature-induced tissue ablation by measuring the mechanical changes in the lesion [15, 16]. HIFU-induced lesions are temporarily seen as hypodense areas in diagnostic ultrasound [17]. However, the real extent of the primary lesion cannot be precisely defined in each case.

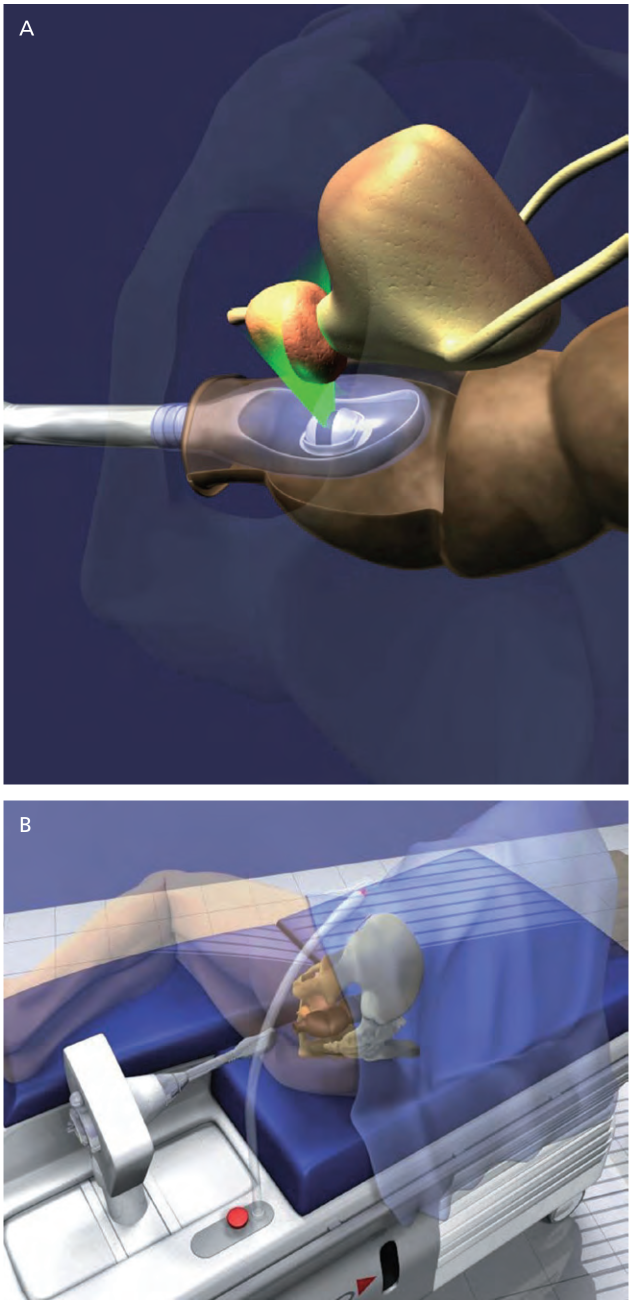


Figure 115.4 (A) Probe positioning. (B) Patient positioning during treatment.

Further characterization techniques based on ultrasound, contrast-enhanced Doppler [18] or different techniques to assess the acoustic behavior of tissues have been proposed to determine the extent of HIFU-induced lesions [19]. Based on a 14-year experience with transrectal HIFU in prostate cancer, it is evident that TRUS can be employed for safe and reproducible HIFU treatment even without "realtime" temperature measurement (Figure 115.5).

Experimental models

The HIFU-based destruction of tissue has been studied in various experimental tumor models. To study the HIFU effect *in vivo*, experiments have been performed on mouse glioma [20], hamster medulloblastoma [21], and the rat Morris hepatoma [22, 23]. DUNNING R3327, as well as AT2 and AT6 carcinomas with high metastatic potential [24, 25], implanted in rats have been studied as models of prostate cancer.

In vitro [26, 27], *ex vivo* [26, 28], and *in vivo* [14, 27, 29] experiments were also performed to study the treatment possibilities with HIFU for kidney tumors. These animal studies provided evidence that cancerous tissue can be destroyed with HIFU without inducing metastasis [25]. Transrectal HIFU for treatment of the prostate was confirmed in experimental canine models [30, 31].

Treatment of bladder cancer

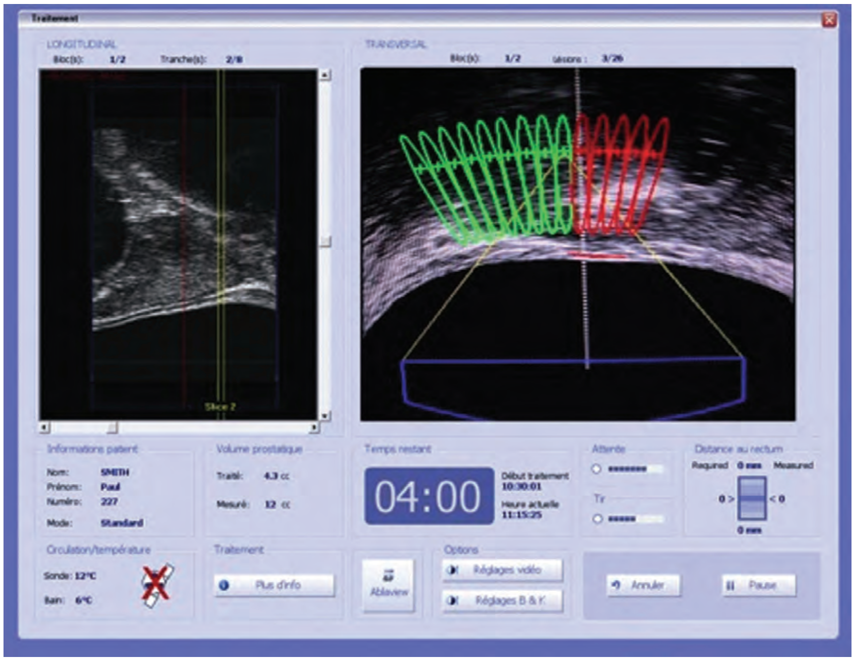
In the 1990s a device, Pyrotech, was developed that allowed the destruction of superficial bladder tumors by percutaneous HIFU [32, 33]. While both experimental and clinical studies confirmed the feasibility of this application, the project was abandoned because of lower success and higher costs in comparison with endoscopic surgical procedures.

Treatment of kidney cancer

After initial animal studies, the application of HIFU for percutaneous management of renal carcinoma in humans is now in the early stage of clinical development. Pilot studies have shown necrosis and volume reduction after HIFU treatment. Treatment of upper pole renal tumors is difficult due to the absorption of ultrasound energy through the ribs [34, 35]. Experiments are ongoing o solve the main problems, e.g. respiratory movement of the kidney, high blood flow which correlates with cooling and shadowing of the ribs. Despite such limitations, preliminary experiments have demonstrated the feasibility of HIFU as a noninvasive treatment of kidney tumors. Promising studies of intra-abdominal or laparoscopic application of HIFU suggest a solution to these problems.

Treatment of other organs

Besides clinically established transrectal HIFU for prostate cancer, there are several additional HIFU applications (pancreatic cancer, thyroid cancer, brain tumors, bone sarcoma) which are mostly MR controlled. HIFU for benign diseases, such as prostate adenoma or glaucoma, is rarely used because of better and more economic surgical alternatives.



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Heure actuelle 11:15:25

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Figure 115.5 Control screen with realtime transurethral ultrasound image overlaid with virtual high-intensity focused ultrasound.

Treatment of prostate cancer

HIFU devices

During recent years transrectal HIFU for prostate cancer has found its way into routine clinical practice with approximately 30 000 patients having been treated with this technique. Initial attempts to treat benign prostatic hyperplasia (BPH) with HIFU have proved less successful [36]. Two devices have been developed for the treatment of prostate cancer. Initial results for Sonablate® (Focus Surgery Inc., Indianapolis, IN, USA) were reported in 2002 [6]. Treatment success with Ablatherm® (EDAP TMS SA, Vaulx-en-Velin, France) in prostate cancer was reported in a European multicenter study in 2003 [37, 38]. The authors reported separately about their experiences in well-defined patient groups and established, on the basis of these results, standardized procedures and protocols for patient management (see below).

Ablatherm equipment

The Ablatherm device has a treatment module that includes the patient's bed, the probe positioning system, the ultrasound power generator, and the cooling system for preservation of the rectal wall (Figure 115.6). There is also a treatment and imaging endorectal probe that incorporates both a bi-plane imaging probe working at 7.5 MHz and a treatment transducer focused at a maximum of 45 mm and working at 3 MHz. Hence, this one probe can be used for all prostate sizes and indications. The transducer has a variable focusing and rectum distance length. Realtime rectal wall control is present; automatic applicator adjustment towards the rectal wall and multiple security circuits exclude accidental focusing on the rectal wall in order to avoid rectal injury. In 2005, modifications were made to the Ablatherm device to incorporate integrated imaging.

Sonablate equipment

The Sonablate system does not include a dedicated bed. Treatment is performed with the patient in the lithotomy position under general anesthesia. Several treatment probes are available and the one used is selected according to the position of the focal point. There is no dual frequency probe that can operate at 3 MHz during the treatment phase and 7.5 MHz for visualization of the gland. Instead, treatment parameters have to be changed with each parabolic applicator for each treatment layer. For a 25 mm or 45 mm focal length probe, the lesion achieved is 10 mm in length × 2 mm in diameter, while for a split beam performed with a 30, 35 or 40 mm focal length probe, the lesion is 10 mm × 3 mm [6]. In addition, the probe is chosen according to the prostate size, with larger glands requiring deeper penetration. Treatment is usually conducted in three consecutive

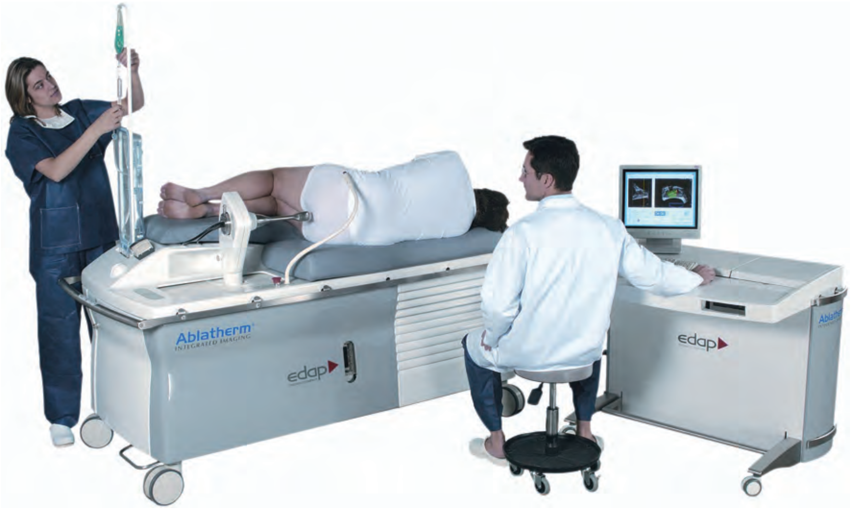

Figure 115.6 Clinical set-up of Ablatherm® (EDAP TMS SA, Vaulx-en-Velin, France).

coronal layers, starting from the anterior prostate and moving in a progressive manner from the apex to the base. As one probe integrates two different twistable parabolic piezoapplicators, there is usually at least one change of probe during the process. No realtime rectal wall distance control is present, leaving it to the operator to perform manually-guided rectal wall orientated HIFU treatment in the peripheral zone, the most likely location of a prostate tumor.

Indications and contraindications

In general, HIFU is indicated for patients with localized prostate cancer (stage T1–T2 N0M0, Gleason score 1–3) who are not candidates for surgery due to their age, general health status, a prohibiting comorbidity, or their decision against radical prostatectomy. However, the indications have been expanded based on clinical experience to include: partial therapy in unilateral low volume, low Gleason score tumors [T1–2a Nx/0M0, prostate-specific antigen (PSA) <20 ng/mL); salvage therapy in recurrent prostate cancer after radical prostatectomy, radiotherapy, or hormone ablation (all T Nx/0M0, all Gleason score/PSA); and advanced prostate cancer as an additional neoadjuvant debulking process (T3–4 Nx/0M0, all Gleason score/PSA).

Other nonsurgical treatment options for localized prostate cancer, such as cryotherapy or brachytherapy, cannot generally be repeated in cases of local recurrence. In comparison, HIFU treatment can not only be repeated but can also be used as a salvage therapy.

A basic contraindication for both devices has been a gland size of larger than 40 mL due to the focal length of the HIFU transducers. However, studies with Ablatherm have shown that larger glands can be downsized through transrectal resection of the prostate (TURP) and therefore a gland size of larger than 40 mL is no longer regarded as contraindication. Contraindications for both devices are a history of rectal fistula as there may be incomplete healing of the fistula, as well as a reduced vascular blood supply to the damaged tissues, making them more prone to injury than normal tissue. Obviously, patients with significant rectal stenosis or rectal amputation are not candidates for HIFU since the probe cannot be placed in the rectum.

Procedure

TURP before HIFU allows the removal of any reflecting/deviating calcifications, abscesses, intravesical middle lobes, and large (>40 mL) adenomas. The generation of a cavity and its subsequent compression by the rectal balloon increases the accessibility of the HIFU waves to the remaining gland (Figure 115.7). TURP should be performed radically and not leave larger adenoma parts [39, 40]. Furthermore, there should be extremely wide resection of the bladder neck and trigonum. This reduces the risk of bladder neck stenosis caused by prostate gland shrinkage after HIFU. The rectal balloon that covers the HIFU probe is then able to “squeeze” the gland to stretch and flatten the rectal wall and to fix it into position. TURP before HIFU has been a standard procedure for most users since 2000 (see below). For most prostate sizes (85%), TURP is performed at the same time as HIFU. Only for glands larger than 40 mL (15%) is TURP conducted 1 month prior to HIFU. In salvage HIFU, TURP is minimal or only a bladder neck incision is performed. In salvage therapy after radical prostatectomy, HIFU is performed without any additional endoscopic intervention.

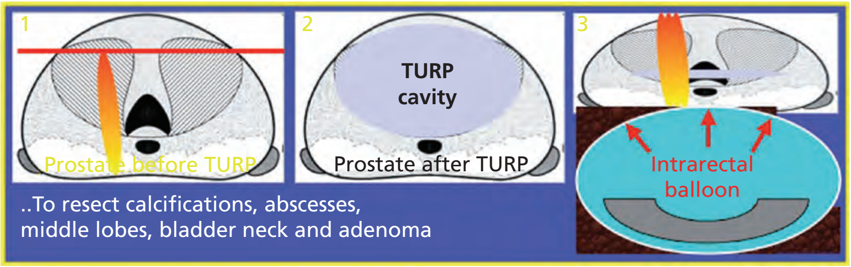
1
2
3
TURP
cavity
Prostate before TURP
Prostate after TURP
Intrarectal
balloon
..To resect calcifications, abscesses,
middle lobes, bladder neck and adenoma

Figure 115.7 Principle of transurethral ultrasound (TURP) before high-intensity focused ultrasound.

Treatment parameters

As mentioned, the treatment parameters that are important for effective tissue coagulation include the power setting (W), piezoelectric frequency (MHz), shot duration, as well as the delay between shots and the number of shots per prostate volume (dose). A delay between shots is necessary to avoid significant accumulation of cavitation bubbles in the tissue. The length and diameter of the lesion to be generated in the prostate need to be considered in treatment planning, as well as the possibility of adapting the treatment parameters to different tissue types (untreated, preirradiated or HIFU pretreated). Consequently, three software modifications facilitate the application of different levels of energy.

Impact on serum prostate-specific antigen

The European multicenter study reported results 1 year after HIFU treatment of 402 patients with localized prostate cancer (T1–2/N0–x/M0) treated between 1995 and 1999 [38]. In total, 87.2% of control biopsies were negative. Stratified according to the prognostic risk, 92.1% were negative in the low-risk group (Gleason score < 7),; 86.4% in the medium-risk group (Gleason score 7), and 82.1% in the high-risk group (Gleason > 7). The PSA nadir was generally found 3–4 months after HIFU treatment. PSA after treatment was significantly influenced by the prostate volume in relation to the completeness of the HIFU treatment. PSA remained stable after treatment during the mean follow-up of 407 days.

Effects on prostate tissue

In a clinical study in which a partial HIFU treatment was performed 1–2 weeks before radical prostatectomy, the efficacy of HIFU was histologically confirmed. The prostate was histologically analyzed after its complete removal. HIFU had been applied to the sites where positive tissue biopsies had been found. The histologic examination of the samples showed a sharp demarcation between the HIFU-treated and -untreated areas, and in the treated areas complete necrosis was found [41].

As mentioned above, the extent of tissue damage caused by HIFU can be determined by gadolinium-enhanced MRI. The treated area appears as a hypodense zone surrounded by a strong 3–8-mm peripheral rim. This corresponds to histopathological findings characterized by a core of coagulation necrosis surrounded by a peripheral zone of inflammation. The treatment-induced MRI changes usually disappear within 3–5 months and the HIFU-induced contraction of the tissue after about 6 months results in small prostates of approximately 5 mL [42].

Efficacy

Summaries of the efficacy and side effects are given in Tables 115.1 and 115.2. In a series of 120 patients with localized prostate cancer and PSA values of less than 10 ng/mL, cancer-free survival rates were examined. These patients were not suitable for radical prostatectomy and had a life-expectancy of 10 years [2]. The calculated cancer-free 5-year survival rate for the average patient population was 76.9%; this was significantly increased to 85.4% in highly differentiated tumors (Gleason score 2–6) compared to 61.3% in poorly differentiated tumors (Gleason score 7–10). There was no significant difference in survival rates calculated in terms of prostate volume or number of positive biopsies. The nadir PSA, which is a basic prognostic factor for the theoretical 5-year survival, was less than 0.5 ng/mL and was found in 86% of the patients.

Blana *et al*. reported a study of 140 patients with localized prostate cancer [1]. These patients had a baseline PSA of 15 ng/mL or less and a Gleason score of 7 or lower. TRUS biopsies 6 months following HIFU treatment were negative in 93.4% of these patients. The mean PSA nadir was 0.07 ng/mL and the PSA was stable at 0.16 ng/mL over a mean observation period of 22 months. In 77% and 69% of patients, there was no biochemical relapse after 5 and 7 years, respectively. Although a satisfactory "cure" rate in patients with low- and medium-risk disease has been observed with HIFU

Table 115.1 High-intensity focused ultrasound: efficacy.

Study	Number	Pretreatment PSA (ng/mL)	Gleason score	Stage	Median follow-up (months)	Negative biopsy rate (%)	Biochemical survival	Retreatment rate (%)
Chaussy *et al.* (2001) [43]	184	12		T1–2 Nx		80	NR	26.1
Gelet *et al.* (2001) [44]	102	8.38 (mean)	54% 2–6 46% 7–10	T1–2	19	75	66% at 5 years (ASTRO)	78.4
Poissonnier *et al.* (2003) [2]	120	5.67 (mean) 100% < 10	64% 2–6 36% 7–10	T1–2	27	86	76.9% at 5 years (ASTRO)	1.4 treatments per patient
Thüroff *et al.* (2003) [37]	402	10.9 (mean)	13.2% 2–4 77.5% 5–7 9.3% 8–10	T1–2	13	87.2	NR	36.7
Blana *et al.* (2004) [45]	146	7.6 (mean)	5 ± 1.2	T1–2 N0M0	22	93.4	84% at 22 months (PSA <1.0 ng/mL)	18.7
Ficarra *et al.* (2006) [46]	30	18 (median)	17% 7 33% 8 37% 9 13% 10	30% T2b 70% T3 70% T3	6	77	90% at 1 year (PSA > 0.3 ng/mL)	0
Poissonnier *et al.* (2007) [47]	227	7.0 (mean)	67% 2–6 33% 7	T1–2	20.5	86	NR	42.7
Blana *et al.* (2008) [48]	140	7.0 (mean)	5.2 ± 1.4	T1–2 N0M0	76.8 (mean)	96.4	77% at 5 years (Phoenix)	29.3
Blana *et al.* (2008) [49]	163	5 (median)	7.9 ± 3.7	T1–2 N0M0	57.6 (mean)	92.7	75% at 5 years (Phoenix)	20.8

NR, not reported.

as monotherapy, combination therapy should be considered for patients with high-risk disease (see below).

In this study, no severe incontinence (grade II–III) was found. Transurethral resection during the follow-up period was required in 12% due to urinary obstruction. In 47.3% of patients, potency was maintained and there were no reports of significant changes in International Prostate Symptom Score (IPSS). The 5-year survival rates in this study correspond to those in the large series of standard treatments of localized prostate cancer [43–50] (Tables 115.1 and 115.2).

Combination therapy

TURP plus HIFU

The most commonly observed side effects of HIFU for prostate cancer include prolonged voiding dysfunction and retention caused by edema, necrosis or bladder outlet obstruction. To reduce the time of urinary diversion and the postoperative morbidity (sludging, obstruction, infection) studies were undertaken to observe the effect of a combination therapy (HIFU and TURP). In 30 patients with localized prostate cancer a one-stage (under the same anesthesia) combination therapy with TURP and HIFU was performed. The mean operative time was 2 h 48 min. The transurethral catheter time was 2 days and the mean hospitalization 3 days. After 6 months, control biopsies were negative in 80% of patients and the median PSA was 0.9 ng/mL. The mean post-treatment IPSS (PIPSS) was 6.7, compared with a pretreatment score of 7.5. Potency was preserved in 73% of patients who had reported no erectile dysfunction before treatment [39].

The benefit of a combination of TURP and HIFU was demonstrated in a series of 271 patients with prostate cancer and an initial PSA of less than 15 ng/mL [40]. Of 271 patients 96 received HIFU monotherapy, while 175

Table 115.2 Morbidity results following high-intensity focused ultrasound.

Study	Number	INC (%)*	ED (%)	FIS (%)	S&S (%)	PR (%)	UTI (%)	CA (days)	Pain (%)
Blana *et al.* (2004) [45]	146	5.8	57.2	0.7	11.7	NR	4.1	SP: 12.7	1.4
Thüroff *et al.* (2003) [37]	402	GI 10.6 GII 2.5 GIII 1.5	13	1.2	3.6	8.6	13.8	F: 5 SP: 34	NR
Gelet *et al.* (2001) [44]	102	GI 8.8 GII 9.8 GIII 3.9	61	1	17	5	NR	9.1	2
Chaussy *et al.* (2003) [40] (no TURP)	96	GI 9.1 GII 4.6 GIII 1.7	40	NR	27.1	NR	47.9	SP: 45.1	NR
Chaussy *et al.* (2003) [40] (TURP)	175	GI 4.6 GII 2.3	31.8	NR	8	NR	11.4	SP: 13.7	NR
Ficarra *et al.* (2006) [46]	30	7	NR	0	10	13	16	SP: 12	NR
Lee *et al.* (2006) [50]	58	GI 16	NR	0	NR	3,4	NR	SP: 15	NR
Poissonnier *et al.* (2007) [47]	227	GI 9.0 GII 3.0 GIII 1.0	39	0	12	9	2	7	3
Blana *et al.* (2008) [48] (multi)	140	GI 5.0 GII 0.7	43.2	0	13.6		7.1	NR	5.7
Blana *et al.* (2008) [49] (single)	163	GI 6.1 GII 1.8	44.7	0	24.5		7.8	NR	3.7

*GI: incontinence grade I, i.e. loss of urine under heavy exercise requiring 0–1 pad/day; GII, incontinence grade II, i.e. loss of urine under light exercise requiring >1 pad/day; GIII, incontinence grade III, i.e. loss of urine under any exercise requiring >2 pads/day.

CA, Postoperative catheter duration; ED, erectile dysfunction; F, Foley catheter; FIS, fistula;, INC, incontinence; NR, not reported; PR, postoperative retention; SP, suprapubic catheter; S&S, stricture and stenosis; TURP, transurethral resection of the prostate; UTI, urinary tract infection.

were treated with combination therapy. The mean resection weight was 15.7 g (2–110 g) and median weight 12.5 g. In 51.6% of the patients, carcinoma was found in the resection material. The mean follow-up time for the monotherapy group was 18.7 ± 12.1 months and for the combination therapy group was 10.9 ± 6.2 months. The histologic results in both groups were similar after treatment, with negative biopsies in 87.7% versus 81.6%. The median PSA nadir was 0.0 ng/mL in both groups. The monotherapy group required a suprapubic catheter for 40 days, while in the combination group it was removed after 7 days.

The rate of adverse events among patients with primary therapy is low (Table 115.2): grade I stress incontinence was observed in 4–6% of patients, grade II in 0–2%, and secondary intermediate infravesical obstruction in 5–10%. Severe incontinence (grade III) and urethrorectal fistulas are rare (<1%). Preservation of erectile function is directly dependent on the position of the primary lesion in relation to the neurovascular bundle. Sparing the contralateral side for neurovascular preservation can improve potency, however this results in a higher retreatment rate [51–54].

Radical prostatectomy after HIFU

Between 1996 and 2000 we performed seven prostatectomies after HIFU. This was due to incomplete HIFU treatments of larger prostates. At this time we did not perform combination therapy with TURP before HIFU. HIFU treatment had caused severe fibrotic adhesions between the rectum and Denovilliers' fascia which posed surgical challenges. In the area of the bladder outlet no changes were observed neither in the lateral nor in the ventral portion of the prostate. While radical prostatectomy after HIFU is more demanding, in our experience it was not associated with higher morbidity compared to a standard prostatectomy.

HIFU after brachytherapy

Limited experience exists of HIFU following brachytherapy. It appears that this approach is not associated with a significant increase in complications compared with primary HIFU. However, it seems advisable to monitor the position of the seeds precisely before HIFU (MR). Seeds should not be outside the prostate capsule and especially not between the rectum and prostate where they will interfere with the direct entry path of the ultrasound.

HIFU after radical prostatectomy

Local recurrence after radical prostatectomy occurs in about 30% of cases. HIFU offers a treatment option when local recurrence can be identified through TRUS and the area is accessible by the therapeutic transducer (depth 25 mm). After treatment with HIFU, the treated areas showed negative biopsies in 77%. The PSA nadir averaged 0.2 ng/mL and 66% of the patients achieved nadir values of 0.5 ng/mL. During follow-up of 5 years, 91% of patients showed no biochemical progress [55, 56].

HIFU after radiation therapy

HIFU has been performed as salvage therapy following external radiotherapy failures. Gelet *et al.* reported results of 71 patients [57]. All patients were diagnosed with a biochemical recurrence and local disease was confirmed by biopsies. In one-third of patients androgen deprivation was employed either as a measure for auxiliary radiotherapy or for early biochemical relapse, prior to HIFU treatment. During follow-up after HIFU for a median of 14.8 months (range 6–86), 80% of treated patients showed negative biopsies . The median PSA nadir was 0.2 ng/mL. Despite these satisfactory results, 40 patients (56.3%) required additional auxiliary treatment. The need for adjuvant therapy resulted from an isolated increase in PSA (36.6%) or the detection of a histologically proven recurrence. In this group, four patients died of metastatic prostate cancer. The high rate of patients with rising PSA despite negative histologic findings may indicate that in this population extraprostatic manifestation can be assumed. In patients with HIFU as salvage therapy after external radiotherapy a significantly higher rate of side effects is observed, compared with patients who undergo primary HIFU therapy. Nevertheless, there is a favorable risk–benefit ratio after HIFU treatment as compared to the alternatives [58].

Palliative therapy

Preliminary results for the palliative treatment of advanced prostate cancer with HIFU are promising in terms of reduction in local morbidity (rectal compression, infravesical obstruction, hydronephrosis, hematuria, pelvic pain syndromes). Unpublished data in several large patient groups ($n > 70$) with T3 and hormone refractory prostate cancer (HRPC) show a post-HIFU PSA velocity of 0.19 ng/mL/year with follow-up of 10 years (without additional hormone ablation). Local tumor ablation with HIFU also resulted in a PSA reduction in 80% of the HRPC cases. There was also evidence of a synergistic effect in hormone ablative therapies, with delays seen in the onset of hormone resistance [55, 59].

Predicting outcome after high-intensity focused ultrasound

The prediction of treatment outcome in patients treated with radical prostatectomy is based on pathologic features such as tumor grade, stage, margin status. Due to the absence of histologic specimens following HIFU, it is necessary to consider other predictors of treatment outcome. PSA nadir as a predictor of clinical failure following HIFU has been shown to be a strong predictor of treatment failure [60]. In a 6-month study involving 115 patients, failure rates following HIFU were 11% (four of 36) in patients with a PSA nadir of 0.0–0.2 ng/mL compared with 46% (17 of 37) in patients with a PSA nadir of 0.21–1 ng/mL and 48% (20 of 42) in patients with a PSA nadir of greater than 1.0 ng/mL. In addition, the PSA nadir was strongly associated with both preoperative PSA level and residual prostate volume. The validity of PSA nadir as a predictor of outcome over a longer follow-up has been reported by Ganzer *et al.* [61]. The median follow-up was 4.9 (3–8.6) years and patients were divided into three PSA nadir subgroups (≤0.2 ng/mL, 0.21–1 ng/mL, and > 1 ng/mL). Treatment failure was defined according to American Society for Therapeutic Radiology and Oncology (ASTRO) criteria. It was shown that the PSA nadir after HIFU correlated highly significantly with treatment failure and disease-free survival rate. Treatment failure rates during follow-up were 4.5%, 30.4%, and 100%, respectively, for the three PSA nadir groups ($P < 0.001$). The actuarial disease-free survival rates at 5 years were 95%, 55%, and 0%, respectively, for the three groups ($P < .001$). These findings suggest that outcome is improved if a PSA nadir of ≤0.2 ng/mL is reached.

Immunologic response after high-intensity focused ultrasound

Recent progress has been made in developing an effective immune strategy for treating prostate cancer. A number of immunotherapy regimens are being studied, including immunomodulatory cytokines/

effectors, peptide and cellular immunization, viral vaccines, dendritic cell vaccines, and antibody therapies. Immunomodulatory agents, such as granulocyte–macrophage colony-stimulating factor (GM-CSF), Flt3 ligand, and interleukin (IL)-2, have been used to stimulate the immune system to generate an antitumor response against prostate cancer. A number of vaccine-based approaches have also been studied based on prostate- or tumor-specific antigens, including PSA, prostatic acid phosphatase, prostate-specific membrane antigen, and prostate stem cell antigen. GVAX® is a cellular vaccine that uses exogenous tumor cells engineered to secrete GM-CSF, which is thought to increase dendritic cell presentation of antigens to the immune system. However, encouraging early preclinical results have not been extended into the clinical setting.

Several studies have looked at the potential of HIFU to initiate an immune response. Wu *et al*. examined the effect of HIFU on systemic antitumor immunity, particularly T-lymphocyte-mediated immunity in cancer patients [62]. A total of 16 patients with solid malignancies were treated with HIFU, including patients with osteosarcoma, hepatocellular carcinoma, and renal cell carcinoma. The results showed a significant increase in the population of CD4(+) lymphocytes and the ratio of CD4(+)/CD8(+) in the circulation of cancer patients after HIFU treatment. The authors concluded that HIFU could enhance a systemic antitumor cellular immunity in addition to local tumor destruction in patients with solid malignancies.

The same group investigated whether the tumor antigens expressed on breast cancer cells could be preserved after HIFU treatment [63]. Primary lesions in 23 patients with biopsy-proven breast cancer were treated with HIFU, and these were then submitted to modified radical mastectomy. Breast cancer specimens were stained for a variety of cellular molecules, including tumor antigens and heat-shock protein 70 (HSP-70). A number of tumor antigens were identified and these may provide a potential antigen source to stimulate antitumor immune response.

It has been suggested that endogenous signals from HIFU-damaged tumor cells may trigger the activation of dendritic cells and that this may play a critical role in an HIFU-elicited antitumor immune response [64]. A mouse model bearing MC-38 colon adenocarcinoma tumors was treated with thermal and mechanical HIFU exposure settings in order to independently observe HIFU-induced effects on the host's immunologic response. Results showed that HIFU elicited a systemic antitumor immune response that was closely related to dendritic cell activation. Dendritic cell activation was more pronounced when tumor cells were mechanically lysed by focused ultrasound treatment.

The status of tumor-infiltrating lymphocytes (TILs) after HIFU ablation of human breast cancer has been investigated [65]. Results show that TILs infiltrated along the margins of the ablated region in all HIFU-treated neoplasms, and the numbers of tumor-infiltrating CD3, CD4, CD8, CD4/CD8 B lymphocytes, and natural killer cells was increased significantly with HIFU treatment. The number of FasL(+), granzyme(+), and perforin(+) TILs was significantly greater in the HIFU group than in the control group.

Focal therapy

Future treatment options for prostate cancer that are being considered include the development of more focused therapy and immunotherapy. The goal of more focused therapy for prostate cancer is to selectively ablate known disease while reducing associated morbidity. In the case of unilateral disease and where potency is an important issue for the patient, it would be advantageous to exclude the contralateral lobe/capsule and neurovascular bundle. Ideally, this would be achieved by excluding 5 mm of tissue on the contralateral lobe and treating only 90% of the prostate. This approach may be appropriate in young patients, with small, low-grade, unilateral tumors. Patients requesting this approach would need to be advised of the risk of tumor recurrence in the untreated area and the requirement for good compliance with follow-up. There are several critical issues that need to be addressed regarding focal therapy of prostate cancer. The first is the accurate identification and localization of the so-called "index lesion" within the prostate on which to focus therapy. There are also issues relating to the effectiveness of focal treatments and how patients should be monitored following treatment, whether this is with PSA, biopsy, or perhaps imaging in the future.

Transperineal three-dimensional (3D) mapping biopsies are considered by some to be more accurate than TRUS-guided biopsies in excluding patients with clinically significant disease outside the areas to be ablated. Transperineal 3D mapping biopsies revealed that of 110 patients shown to have unilateral disease on standard TRUS biopsy, 60 (55%) had, in fact, bilateral cancer [66]. The Gleason score on 3D biopsy was also higher in 25 patients (23%) over the original findings, indicating that transperineal prostate mapping may provide better pathologic assessment of the entire prostate gland. The localization of tumor within the gland both before and after treatment is another important issue. The application and continued development of a variety of imaging techniques are likely to provide improvements in the visualization and assessment of HIFU lesions in the near future. With regard to localizing disease, variable sensitivity of MRI has been reported [67]. Functional imaging techniques, such as dynamic contrast-enhanced (DCE) MRI, diffusion-weighted imaging (DWI), and magnetic resonance spectroscopic imaging (MRSI), have been evaluated in an attempt to improve the detection and localization of prostate cancer [68–70]. Results suggest that vascular information from DCE-MRI or DWI-MRI combined with metabolic data from MRSI have extremely good potential for improving the accuracy of defining and staging prostate cancer.

In terms of assessing the efficacy of HIFU treatment, MRI is the gold-standard technique and the extent of necrosis can be clearly visualized on gadolinium-enhanced T1-weighted images [42, 71]. MRE may also provide a means of assessing the effects of thermal tissue ablation by measuring the mechanical properties of the lesion [72]. HIFU-induced lesions are visible using standard ultrasound [17], although there are limitations to the accuracy of this approach. Other ultrasound-based techniques that may prove useful for assessing the extent of HIFU-induced lesions include contrast-enhanced power Doppler [18] and other techniques that characterize the acoustic properties of tissues.

Focal therapy has been compared with whole-gland ablation in a series of 70 patients [73]. Of the 29 patients with unilateral disease, focal therapy involved ablation of the total peripheral zone and half of the transitional zone, and resulted in a 77% negative biopsy rate at 12 months. Of the remaining 41 patients with bilateral disease, whole-gland ablation resulted in an 84% negative biopsy rate at 12 months. Two-year biochemical recurrence-free survival rates were 91% and 50% for low- and intermediate-risk groups undergoing whole gland ablation, respectively, compared with 83% and 54%, respectively, for the focal therapy equivalents. Morbidity with the two forms of HIFU was comparable.

Conclusions

HIFU is an evolving and effective treatment for prostate cancer [74], with a wide range of indications in all tumor stages. HIFU is indicated for localized prostate cancer (stage T1–T2 N0M0, Gleason score 1–3) and partial therapy is being explored for low volume, low Gleason score tumors. Furthermore, it has been successfully used as salvage therapy in recurrent prostate cancer after radical prostatectomy, radiotherapy, and hormone ablation, and as a debulking approach in advanced prostate cancer. While other nonsurgical treatment options for localized prostate cancer (e.g. cryotherapy or brachytherapy) cannot generally be repeated in cases of local recurrence, HIFU can be repeated. Postprocedural morbidity is low; however, clinically significant complications can occur, including incontinence and erectile dysfunction. However, specific measures can be taken to avoid the latter. HIFU is an effective treatment for patients with localized prostate cancer and can also be considered for patients with metastatic disease. Promising advances in HIFU include new treatment strategies for specific patient groups.

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CHAPTER 116

Cryotherapy of the Prostate

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Introduction

Cryosurgery has been used in cancer treatment since the 1850s when rudimental frozen salt solutions were applied to advanced cancers with reported reduction in tumor size [1]. Since then, technologic advances have allowed for the evolution of cryosurgery into its current form whereby it represents a recognized option for the treatment of prostate, kidney, and other cancers. In this chapter we discuss the principles of cryobiology, current indications for cryotherapy of the prostate, and procedure details, and summarize the outcomes as reported in the literature.

Cryobiology: general principles

Cryogenic injury

It is common knowledge that freezing can cause tissue destruction, e.g. frostbite. The mechanisms underlying this effect can be summarized in two categories: direct cellular injury and vascular cryogenic injury [2].

Direct cellular injury has been extensively studied in cell culture models and is based on water biophysics and ice formation within the frozen tissue. Two separate mechanisms of ice formation have been described [2, 3]. Extracellular ice formation occurs as the freezing propagates through the tissue and is responsible for an increase of solute concentration in the extracellular space, causing cell dehydration [4] which disrupts enzymatic processes and alters cell membrane properties (solution-effect injury) [5]. The second direct injury mechanism is represented by intracellular ice formation that occurs at high freezing rates (rapid freezing) and allows for water entrapment within the cell before dehydration has occurred. Intracellular ice formation alters cell physiology by disrupting membranes and contributes to cell death by direct cryogenic injury. Increasing the duration of exposure to lethal temperatures (–40°C) enhances the efficacy of tumor cell destruction [6] as very little water remains unfrozen at temperatures below –40°C [7]. During thawing additional mechanisms of damage contribute to tissue destruction. Recrystallization occurs when temperature rise above –40°C. In the recrystallization process, smaller ice crystals fuse to form larger structures that inflict additional damage on cell structures. Moreover, as extracellular ice crystals melt, a hypotonic extracellular environment is created and water is pushed into the cells and may inflict further membrane damage by volume overload [3]. It has been suggested that passive thawing may be more efficient in prostate cancer destruction [6].

The second category of cryogenic injury is the vascular mechanism (Figure 116.1). This type of cryogenic injury occurs preferentially in the microcirculation where endothelial cell damage and sloughing along with vessel wall distention, increased vessel permeability, stasis, and thrombosis determine ischemia and inflammation, and contribute to tissue necrosis [2]. Additionally, thawing and reperfusion injury mediated by free radicals augment the endothelial damage and enhance the inflammatory process and enzymatic degradation of cell debris.

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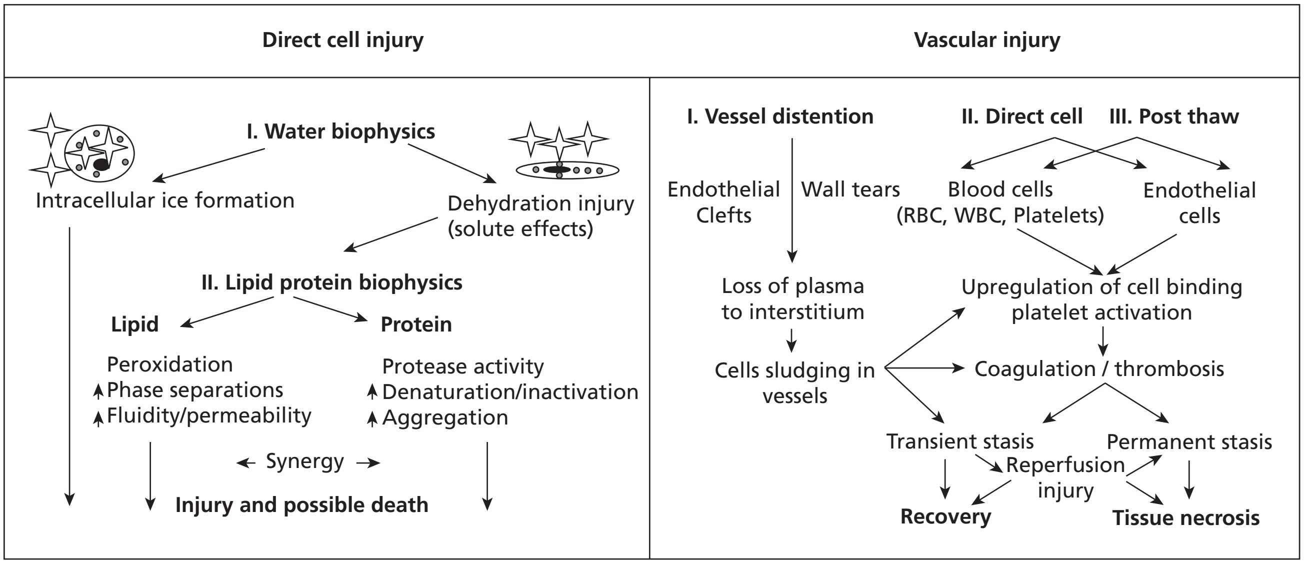
Direct cell injury
Vascular injury
I. Water biophysics
Intracellular ice formation
Dehydration injury (solute effects)
II. Lipid protein biophysics
Lipid
Protein
Peroxidation
↑Phase separations
↑Fluidity/permeability
Protease activity
↑Denaturation/inactivation
↑Aggregation
Synergy
Injury and possible death
I. Vessel distention
II. Direct cell
III. Post thaw
Endothelial Clefts
Wall tears
Blood cells (RBC, WBC, Platelets)
Endothelial cells
Loss of plasma to interstitium
Upregulation of cell binding platelet activation
Cells sludging in vessels
Coagulation / thrombosis
Transient stasis
Permanent stasis
Reperfusion injury
Recovery
Tissue necrosis

Figure 116.1 Direct and vascular cryogenic injury. RBC, red blood cell; WBC, white blood cell (adapted from Hoffmann and Bischof [2], with permission).

Cryogenic injury progresses as the temperature drops and is a time-dependent process. While cell dehydration occurs at temperatures between 0°C and –20°C, this effect alone may induce only a reversible cellular injury. Intracellular ice begins to form at temperatures below –15–20°C and at –40°C induces lethal effects on the cell [8]. Therefore, tissue that reaches –40°C and below will usually be effectively destroyed (lethal or killing zone), but surrounding tissue that does not reach this threshold is affected by sublethal, reversible cryogenic injury (Figure 116.2). At the edges of the lethal zone, apoptosis represents an additional mechanism of cell death. Apoptosis seems to peak several hours after the cryogenic stimulus has been removed [9].

Understanding the mechanisms of cryogenic injury is essential to be able to propose potential cryosensitizers, i.e. agents potentially able to increase the efficacy of cryotherapy or target cell destruction with more precision, limiting it to cancer tissue while sparing surrounding structures.

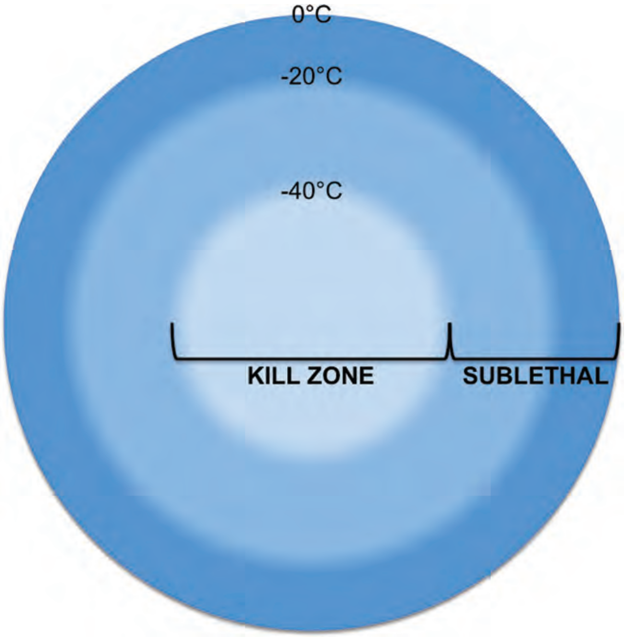
0°C
-20°C
-40°C
KILL ZONE
SUBLETHAL

Figure 116.2 Lethal and sublethal zones during cryoinjury. The sublethal zone represents a spectrum whereby cryoinjury may be reversible: the colder the temperature achieved within this temperature gradient, the less likely the cancer cell can survive.

Cryoimmunology

In contrast to conventional surgical extirpation whereby tissue is removed from the organism, cryotherapy-induced cellular destruction releases antigenic structures that are processed by immunocompetent cells and may elicit an immune response. However, the entity of such a response is debated. Reported data are controversial, suggesting that the elicited immune response may be either immune-stimulating [10–13] (promoting the destruction of residual local or metastatic deposits) or immunosuppressive [14, 15] (inducing tolerance to the presented antigens). The nature of the immune reaction is likely dependent upon local factors such as cytokine response induced by cryoablation, the type of antigen-presenting cells (dendritic cells vs macrophages), and the antigen in a form that may be presented by the competent cells [16].

While the potential of evoking a specific immune anticancer response is intriguing, preclinical data are controversial and further research is needed to be able to exploit this aspect of cryoablation to potentially increase the efficacy of tumor destruction.

Indications for Cryotherapy of the Prostate

Primary cryoablation

Primary cryoablation is considered an option for the treatment of localized prostate cancer. The American Urological Association's (AUA) Best Practice Statement from 2008 considered cryosurgery to be an option for patients who either do not desire or are not good candidates for conventional radical surgery [17]. The European guidelines state that cryosurgery is an experimental therapeutic option for clinically localized prostate cancer [18].

The European Association of Urology (EAU) guidelines define as ideal candidates patients with organ-confined prostate cancer, or having minimal extension beyond the prostate, prostate volume 40 mL or smaller, prostate-specific antigen (PSA) less than 20 ng/mL, and Gleason score less than 7, although intermediate-risk patients may represent potential candidates as well [18]. Large prostates can benefit from neoadjuvant hormonal therapy to reduce the size of the gland, although the effect of this approach on subsequent outcomes remains to be determined. The Best Practice Statement from the AUA [17] indicates cryosurgery as an option for low-, intermediate-, and high-risk clinically localized prostate cancer, setting no apparent limits to PSA values, clinical stage or biopsy Gleason score. However, this document does not specifically address the suitability for cryosurgery of high-risk patients who may require multimodality treatment.

Other than disease characteristics (PSA, Gleason score, clinical stage), additional factors should be considered when evaluating potential candidates for primary cryoablation. History of transurethral resection of the prostate represents a relative contraindication for cryosurgery. Large defects in the prostatic fossa may reduce the effectiveness of the protective urethral warmer and thereby increase the chance of urethral mucosa sloughing. Similarly, the presence of major rectal pathology may constitute a relative contraindication for cryoablation. In addition, since impotence is a common outcome after whole-gland cryosurgery, potent patients concerned with erectile function should be preoperatively counseled about realistic expectations with this approach.

The apparent lack of strong recommendations in the guidelines derives from a paucity of clinical data and long-term outcomes of primary cryosurgery. Therefore, more research is needed before solid recommendations can be made. Nevertheless, it seems that the experts agree that suitable candidates are those who fall into the low–intermediate risk categories. It is reasonable to presume that patients with low-risk disease are likely to have better outcomes, similarly to conventional surgical treatment.

In summary, primary cryoablation represents an alternative minimally invasive treatment option for localized prostate cancer. Patients with low- and intermediate-risk disease who are unsuitable for conventional radical surgical treatment likely represent the ideal candidates for cryosurgery. Cryosurgery may also be considered as primary treatment in appropriately selected high-risk prostate cancer patients as an alternative to conventional treatment.

Salvage cryoablation

Salvage cryosurgery after radiation therapy failure has been proposed as an alternative to salvage radical prostatectomy with the potential of less morbidity. Salvage cryoablation has been reported after interstitial therapy as well [19]. Few data are available in the literature with regards to the outcomes of salvage cryosurgery. Potential candidates for salvage cryoablation are those with biopsy-proven locally recurrent prostate cancer after primary radiation or ablative therapy in the absence of metastatic disease.

Candidates for salvage cryoablation after radiation failure include patients with biochemical failure post primary radiation therapy according to current definitions of biochemical failure (ASTRO, Phoenix) and prostate biopsy demonstrating locally recurrent disease with no clinical or radiologic evidence of distant metastases. Biopsies of the seminal vesicles in this setting are recommended, as seminal vesicle involvement may preclude a successful salvage cryoablation with curative intent. Lymph node sampling may be considered as part of the evaluation in high-risk patients.

Factors associated with the success of salvage cryoablation include: low PSA values (<4 ng/mL) at the time of salvage cryoablation [20, 21] and at the time of primary therapy [22]; PSA nadir after primary therapy [22]; PSA doubling time [21]; and low Gleason grade of the recurrent disease [20].

Based on these data, the optimal candidate for salvage cryosurgery is a patient with biopsy-proven locally recurrent prostate cancer with no evidence of distant spread or seminal vesicle involvement, a PSA less than 4 ng/mL, PSA doubling time greater than 16 months, with favorable primary disease characteristics (low PSA, low Gleason score).

Cryoablation procedure

As technology has improved over the years, we discuss only the current third-generation technology, leaving the description of previous techniques (first and second generations) to historical reference.

Third-generation cryotechnology is based on dual-gas systems exploiting the Joule–Thompson principle of gas expansion to provide heat subtraction and delivery through small caliber cryoprobes. The same effect is used in home appliances, such as air conditioning systems and refrigerators. Briefly, these systems use pressurized argon and helium gases delivered to the cryoprobe in a closed circuit. When argon gas is allowed to expand through a pinhole opening at the tip of the cryoprobe, the gas changes its internal energy state as the pressure drops and the process consumes energy thereby reducing the temperature. The inverse process happens during thawing whereby helium is expanded in the cryoprobe, thus releasing energy and heating the probe. The opposite effects achieved with the two gases derive from different molecular properties (internal energy) of argon and helium gases, based on attractive and repulsive forces of gas molecules. The latest technology introduced an argon-only system whereby both freezing and thawing phases are achieved by altering the physical properties of argon, thus simplifying the technologic complexity of cryoablation and obviating the need for an additional gas.

The cryoablation suite consists of a console that monitors and controls the procedure, argon (and sometimes helium) pressurized gas tanks, a urethral warming device, and peripherals (transrectal stepper-mounted ultrasound, cryoprobes, and thermocouples). The system's user interface integrates ultrasonographic imaging that guides cryoprobe positioning and monitors the formation of the ice ball, receiving input from the urethral warmer and the temperature probes.

Different numbers, positions and configurations of probes allow for sculpturing of the ice ball with precision. Cryoprobes and thermocouples are positioned transperineally through a brachytherapy-like template (Figures 116.3 and 116.4). Currently, thin and ultrathin (17G, 1.5 mm) cryoprobes are available. Ice-ball formation is monitored both by temperature probe readings and by realtime ultrasound.

Cryoablation is typically an outpatient procedure and can be performed under general, spinal or locoregional anesthesia. With the patient in lithotomy position, probes are positioned using the grid under the guidance of transrectal ultrasound. Thermocouples are typically positioned adjacent to the neurovascular bundles, sphincter, and Denonvilliers' fascia to assist with ice-ball monitoring. After probe positioning, flexible cystoscopy is used to verify that the probes have not penetrated the urethra or bladder. The urethral warming device is then introduced over a super-stiff guidewire. Although some surgeons place a suprapubic tube to provide bladder drainage in the postoperative period, a urethral catheter can alternatively be utilized at the end of cryoablation, replacing the urethral warming device. Freezing proceeds in an automated manner, using dual freeze–thaw cycles, monitored by ultrasound and thermocouple readings.

Cryoablation results in acute swelling of the prostate that typically resolves in 1–2 weeks, during which time a urethral catheter (or a suprapubic tube) provides bladder drainage. After a successful voiding trial, the catheter can be removed. We recommend assessing

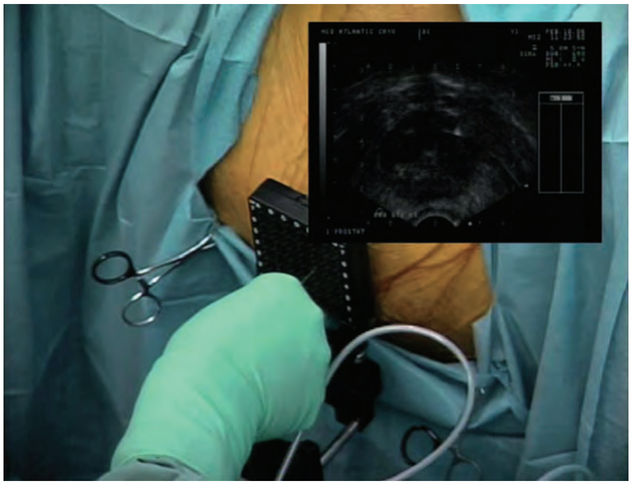

Figure 116.3 Transperineal cryoprobe positioning using a brachytherapy-like template under ultrasound guidance. Stepper-mounted ultrasound probe with template and cryoprobes.

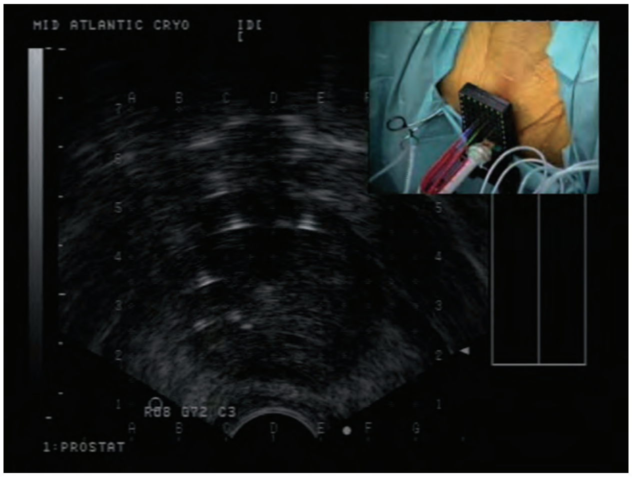

Figure 116.4 Cryoprobes positioned with ultrasound guidance.

Table 116.1 Complication rates after primary cryoablation of the prostate using third-generation technology.

		Complication rate (%)							
Study	Number of patients	Slough	Perineal pain	Urinary retention	UTI/ sepsis	Urethral stricture	Fistula	incontinence	ED
Bahn *et al.* [51]	210	NR	NR	3	NR	NR	2.4	9	41
Shinohara *et al.* [52]	102	NR	3	23	3/3	NR	1	4 (15*)	86
Han *et al.* [26]	106	5	2.6	3.3	0	NR	0	3	87
Wake *et al.* [23]	100	1	NR	20	NR	2	0	8	NR
DiBlasio *et al.* [30]	78	NR	NR	NR	NR	1	NR	7.7	84.6
Cohen [53]	98	2	NR	NR	NR	NR	0	0	NR
Prepelica *et al.* [54]**	65	NR	0	3.1	NR	NR	0	3.1	NR
Hubosky *et al.* [25]	89	2	6	4	1/0	NR	1	2	NR
Donnelly *et al.* [38]	117	NR	NR	15.4	NR	NR	NR	32.5	70.9
Chin *et al.* [37]***	33	NR	32	NR	NR	NR	NR	7	29

*Including patients who underwent transurethral resection of prostate following cryoablation.
**High-risk patients.
***Locally-advanced disease.
UTI, urinary tract infection; ED, erectile dysfunction; NR, not reported.

voiding ability within 1 week postoperatively as in our experience most patients are able to spontaneously void by that time.

Outcomes

Complications of primary cryoablation

Despite its minimally invasive nature, primary cryoablation of the prostate is not devoid of complications. Minor self-limiting complications that are often overlooked in the scientific literature include transient scrotal or penile swelling and penile paraesthesia, which can be reported in up to 10% of patients [23, 24]. These typically occur within 2–3 weeks post procedure and resolve in 2–6 months. Table 116.1 reports a literature summary of complications after primary cryoablation.

Urethral mucosal sloughing is rare and in most series is reported to occur in less than 5% of patients. The incidence of rectourethral fistula today is also low (0–2.4%). Urinary incontinence requiring pads has been reported to occur in less than 10% of patients and is typically transient. The incidence and presentation of incontinence has been reported using various definitions, with most studies not distinguishing between stress, urge, and mixed incontinence, making it challenging to derive precise conclusions. The incidence of urinary retention has varied widely across the literature and requires further evaluation as technical differences may have accounted for this discrepancy between studies. However, the majority of urinary retention events are transitory and resolve within 2–4 months. The more recent series suggest urinary retention may occur in less than 5% of cases [25, 26].

A recent report based on the CaPSURE database analyzed the incidence of urethral stricture after primary therapy for prostate cancer [27]. The overall incidence of stricture after primary cryosurgery was 2.5%. At 1, 2, and 4 years, 96%, 95%, and 87%, respectively, of cryotherapy patients were stricture free, respectively. These data compare favorably to other treatment options: incidence of stricture formation 1.1% for watchful waiting, 2% for androgen-deprivation therapy 2%, and 8.4% for radical prostatectomy [27].

Currently, the available data are limited both due to many of the reported series being updates of previous studies and because data collection has not been standardized, thus precluding a detailed and accurate description of complications after cryoablation. Researchers should strive to better collect follow-up information to delineate accurately the complications profile and determine risk factors for these adverse events.

Complications of salvage cryoablation

A summary of complications after salvage cryoablation is outlined in Table 116.2. Overall, the complication profile appears similar to that for primary cryoablation (see Table 116.1), with the exception of higher incontinence and pelvic pain rates. Overall, salvage cryoablation offers a complication profile that compares well with other salvage techniques. A recent review of the literature concluded that salvage cryoablation offers a viable alternative to the technically challenging salvage

Table 116.2 Complication rates after salvage cryoablation using third-generation cryotechnology.

		Complication rate (%)							
Study	Number of patients	Slough	Perineal pain	Urinary retention	UTI/ sepsis	Urethral stricture	Fistula	Incontinence	ED
Ng *et al.* [20]	187	NR	14	21	10	2.1	2	40	NR
Han and Belledugrun [55]	29	NR	NR	NR	NR	NR	0	7	NR
Ismail *et al.* [22]	100	2	4	2	NR	NR	1	13	86
Pisters *et al.* [56]*	279	NR	NR	NR	NR	NR	1.2	4.7	69.2
Ghafar *et al.* [24]	38	0	39.5	0	2.6	NR	0	7.9	NR
Cresswell *et al.* [57]	20	NR	NR	4	NR	NR	0	4	86
Bahn *et al.* [58]	59	NR	NR	NR	NR	NR	3.4	8	NR

*Series includes a portion of cases treated using second-generation technology.
UTI, urinary tract infection; ED, erectile dysfunction, NR, not reported.

radical prostatectomy, and thus is recognized as an established option in radiorecurrent prostate cancer [28].

Functional outcomes: continence and potency

Continence and potency outcomes are outlined in Tables 116.1 and 116.2. Erectile dysfunction is highly prevalent after whole-gland primary and salvage cryoablation. Therefore, the desire to preserve potency should be carefully considered when discussing whole gland cryoablation as a management option for localized prostate cancer.

Continence is preserved after salvage cryoablation in the vast majority of patients. Most series report a less than 10% incidence of urinary incontinence (Table 116.2). A recent analysis of urinary function after primary and salvage cryoablation using validated instruments has shown excellent functional outcomes [29]. In this study, salvage cryoablation demonstrated inferior urinary function results compared to the primary setting. However, the authors showed that International Prostate Symptom Score (IPSS) and bother index (BI) score worsened immediately after the procedure but recovered steadily thereafter, and the improvement (compared to preoperative values) persisted at 12 months post procedure. Another group reported no significant changes in AUS symptom score (AUASS) after primary cryoablation [30]. These studies suggest that cryoablation does not negatively impact urinary function. On the contrary, urinary function may be improved after cryoablation and this effect can be appreciated 6 months postoperatively.

Prostate cryoablation has acceptable functional outcomes both in the primary and salvage setting. In the salvage setting, cryoablation compares well with salvage surgery and other treatment modalities for recurrent prostate cancer. Salvage cryotherapy is less technically challenging compared to surgery, offers acceptable oncologic and functional outcomes whereas surgery for radio-recurrent prostate cancer remains a highly morbid approach.

An analysis of quality-of-life outcomes after primary and salvage cryoablation has shown similar results in terms of physical symptoms, sexuality, and bowel symptoms evaluated using standardized questionnaires [31]. This study has also demonstrated sexual dysfunction and urinary symptoms to be the most prominent and bothersome symptoms. Severe erectile dysfunction was reported in 86% and 90% of primary and salvage cryoablation patients. These quality-of-life outcomes are comparable to those reported in radiotherapy series [32, 33]. Finally, a recent randomized trial comparing quality-of-life outcomes for primary cryoablation versus external beam radiation concluded that there is no long-term advantage for either treatment, with the exception of sexual function outcomes which favor radiation therapy [34].

Cancer control outcomes

Tables 116.3 and 116.4 outline the reported cancer control outcomes of primary and salvage cryoablation, respectively. There is sensible variability in the definition of biochemical recurrence in the literature, from PSA cut-off values (0.4, 0.5, 1.0 ng/mL) to American Society for Therapeutic Radiology and Oncology (ASTRO; three consecutive PSA rises [35]) and Phoenix (nadir +2 [36]) criteria. Biochemical failure criteria used in conventional radical surgery are not suitable for cryoablation, as with the use of urethral warming devices a portion of prostatic tissue is variably spared and undetectable PSA values are rarely sustained after cryoablation. Currently, there is no consensus on the definition of biochemical failure after cryoablation and the use of diverse definitions in the literature makes for a challenging accurate comparison of the reported outcomes.

Table 116.3 Oncologic outcomes of primary cryoablation.

Study	Number of patients	Definition	Biochemical disease-free survival (%)			
			1 year	3 years	5 years	7 years
Hubosky *et al.* [25]	89	ASTRO	94	–	–	–
		≤ 0.4	70	–	–	–
DiBlasio *et al.* [30]	78	ASTRO	97.9	95.7	71.1	–
Prepelica *et al.* [54]*	65	ASTRO	83.3***	–	–	–
Cresswell *et al.* [57]	31	≤ 0.5	60	–	–	–
Donnelly *et al.* [38]	117	Nadir + 2	–	82.9	75	–
Bahn *et al.* [51]**	590	ASTRO	–	–	–	89.5
Jones *et al.* [59]**	1198	ASTRO	–	–	77.1	–

*High-risk patients.
**Not pure third-generation technology.
***Median follow-up of 35 months.

Table 116.4 Oncologic outcomes of salvage cryoablation.

Study	Number of patients	Definition	Biochemical disease-free survival (%)			
			1 year	3 years	5 years	7 years
Ng *et al.* [20]	187	Nadir + 2	–	–	56	–
Ghafar *et al.* [24]	38	Nadir + 0.3	86	74	–	–
Ismail *et al.* [22]	100	ASTRO	83	59	–	–
Cresswell *et al.* [57]	20	≤ 0.5	66.7	–	–	–
Bahn *et al.* [58]*	59	≤ 0.5	–	–	–	59
Pisters *et al.* [56]*	279	ASTRO	–	–	59	–

*Not pure third-generation technology.

Despite the variations in the definitions of biochemical failure, available data suggest acceptable oncologic outcomes with regards to biochemical disease-free survival of up to 5 years. Data are yet to mature on metastatic progression and cancer-specific survival along with long-term (10–15 years) local cancer control. Most available series are either single institution or single surgeon, or report pooled data for several surgeons. The only two randomized clinical trials of primary cryoablation compared to external beam radiation provide discordant conclusions [37, 38]. While Chin *et al*. found significantly poorer oncologic outcomes for cryoablation [37], Donnelly *et al*. in a larger clinical trial suggested that the two approaches provide comparable biochemical disease-free survival [38]. Of note, the former trial enrolled exclusively patients with locally advanced disease (clinical stage T2c–T3b), whereas the latter explicitly excluded patients with bulky T3 prostate cancer. Moreover, the strength of the results of Chin *et al*.'s study is limited by its sample size [37].

In summary, from the available data, it appears that primary cryoablation offers overall solid cancer control outcomes. In the salvage setting, the outcomes are competitive with salvage prostatectomy and, combined with a favorable morbidity profile, suggest that cryoablation is a first-line treatment option for radiorecurrent prostate cancer in appropriately selected patients. Further research is required to formulate a solid definition of biochemical recurrence considering the unique aspects of cryoablation. Definitions borrowed from radiotherapy, albeit useful in the absence of alternatives, cannot be fully adapted to the cryoablation field. As experience with current cryotherapy technology grows, we are likely to see long-term results in the near future.

Future directions: Focal therapy

The utilization of probe-based ablation has introduced the possibility of treating less than the whole gland. The concept of focal therapy, i.e. treating known foci of cancer while sparing unaffected portions of the gland, thereby potentially preserving a better quality of life, has recently gained interest [39–41]. Hemiablation of the prostate in patients with unilateral or unifocal prostate cancer potentially spares at least one neurovascular bundle and therefore has the ability to achieve much better erectile function outcomes compared to whole-gland cryoablation. A series of 60 patients treated with focal cryoablation reported 72% potency rates after the procedure [42]. Another group showed a 88.9% preservation of potency after focal cryotherapy [43]. Biochemical disease-free survival rates range between 84% and 96% after 28–70 months of follow-up [43–46]. The preliminary results of focal cryoablation indicate a low morbidity profile and acceptable cancer control [45]. However, no randomized trials are available to evaluate the focal cryoablation approach under strict criteria.

Appropriate candidate selection represents probably the main obstacle to a widespread diffusion of focal therapy as a concept. Currently, available imaging tools are insufficient to reliably and accurately detect and map cancerous foci within the prostate [47]. Extensive biopsy schemes are, at this moment, the best means to accurately depict the extent of the gland's involvement by cancer and thereby select appropriate candidates for focal therapy [48]. Novel imaging techniques are being developed and show promising results with a potential role as selection tools in the setting of focal therapy [49, 50].

Focal therapy represents an attractive concept and initial results are encouraging. The interest in this approach is evident but the results are still immature. No consensus exists on methods or criteria of patient selection. The urologic community is awaiting more data to investigate the place of focal therapy among the already established management options for localized prostate cancer.

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CHAPTER 117

Contrast-Enhanced Ultrasound in Urology

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Introduction

Imaging in endourology is mainly comprised of gray-scale ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and skeletal scintigraphy. All of these modalities have their own place in urology, and in this chapter we focus on contrast-enhanced ultrasound (CEUS) as it compares with MRI and CT imaging.

CT scans are commonly used in the diagnosis, staging, and follow-up of urologic malignancies. In the diagnosis of kidney tumors, ultrasound is mainly used for a first screening and in most cases, CT is utilized to make the final diagnosis. MRI is commonly used to evaluate adrenal tumors and cystic lesions in the kidney, and to stage renal cell and prostate carcinoma. For some urologic indications, MRI is used when CT is contraindicated.

The downside of CT and MRI is that they are relatively expensive and less available. Furthermore, CT and MRI contrast agents can have severe side effects [1–3]. CT contrast agents are iodine based and in patients with renal insufficiency these agents can worsen the existing renal function. CT is also associated with significant radiation exposure. Although MRI does not exposure patients to ionizing radiation, MRI contrast agents are gadolinium based and in patients with severe renal failure these agents can cause nephrogenic systemic fibrosis (NFS) [2].

Ultrasound is a safe method to investigate the kidney, bladder, prostate, scrotum, and penis. It has high resolution, offers realtime imaging, is easily available, can be used at the bedside, and is a relatively inexpensive imaging technique.

For diagnosing scrotal abnormalities, ultrasound is the investigation of choice. When used appropriately, ultrasound can distinguish between the most common scrotal abnormalities [4, 5] Doppler investigation allows direct evaluation of testicular perfusion, making it ideal to further distinguish between scrotal abnormalities. However, the diagnostic accuracy of gray-scale and Doppler ultrasound for malignant processes of the kidney, bladder, and prostate is low. For the bladder and kidney, it is mainly used as a screening tool, and for prostate cancer its main role is to guide systematic biopsies.

Malignancies are associated with neovascularization and therefore changes in perfusion [6, 7]. If these changes can be visualized, this may increase the sensitivity and specificity of tumor detection and the accuracy of staging. Suitable techniques for perfusion imaging are dynamic or contrast MRI, contrast CT, and CEUS.

CEUS was first described in 1968 during the imaging of the aortic root [8]. After an injection of saline, it was noted that the small air bubbles present in the saline enhanced the ultrasound signal significantly. Thereafter, attempts to use free air bubbles as an ultrasound contrast agent have been conducted. However, the main problem was the short lifetime of these bubbles. During the last decade, new ultrasound contrast agents have been developed that consist of small ($<8\,\mu m$) encapsulated gas-filled microbubbles. Due to the shell around the gas bubbles, their lifetime is substantially increased. Currently available contrast agents have a lifetime of

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several minutes, and thus with a simple intravenous injection the contrast will become visible in urologic organs. The first application of CEUS was in cardiology for the visualization of myocardial perfusion, and currently its usage is extended to imaging of the liver, breast, kidney, and prostate [9–14].

When microbubbles are exposed to sound waves they are compressed and subsequently expanded as a result of the changing ultrasound pressure. With low-energy ultrasound waves, the bubbles expand linearly, and behave like additional bloodstream reflectors, resulting in increased reflected ultrasound energy. This mode is especially useful in Doppler ultrasound imaging [15].

With medium energy waves the bubbles expand nonlinear which results in reflected signals that not only encompasses the transmitted ultrasound frequency, but also additional harmonics. Currently available contrast-specific imaging techniques utilize these harmonics to distinguish between the reflections of the bubbles and tissue, and sensitive imaging of perfusion is now possible.

At high energy, still within the normal range as applied clinically, the bubbles will disrupt in the imaging plane, and this can be used to visualize a new inflow of contrast. This technique, very useful to detect fast enhancement of tissue, is called destruction-replenishment [16, 17].

In general, ultrasound contrast agents are safe. In Europe over 6000 CEUS investigations of the prostate were reported, without any side-effects [18]. However, side-effects have been reported and the most severe were allergic reactions to the ultrasound contrast agents [19]. The most commonly reported side-effects are rare and usually transient: altered taste, pain at the side of injection and generalized flushing. A paper by Wink et al concludes that in general ultrasound contrast agents are very safe [18].

Contrast-enhanced ultrasound of the prostate

Prostate carcinoma is the most common malignancy in the male population in the western world, and accurate diagnosis and staging is still problematic [20, 21].

Transrectal ultrasound (TRUS) was introduced in 1968 by Watanabe *et al*. [22]. Currently, TRUS is mostly used for guiding systematic biopsies. At first only hypoechoic lesions were biopsied as these were presumed to be the main presentation for prostate carcinoma. However, studies demonstrated that these lesions have only a 17–57% chance of being malignant and that as many as 30% of prostate carcinomas are isoechoic [23, 24]. Therefore, the systematic biopsy protocol was introduced. Hodge *et al*. described the ultrasound-guided sextant biopsy protocol, which has become the most frequently used protocol, with sensitivity and specificity in the ranges of 39–52% and 81–82%, respectively [24, 25].

As stated previously, malignancies are associated with neovascularization and therefore an increased microvessel density (MVD). Siegal *et al*. reported an approximate twofold increase in MVD in prostate carcinoma in comparison to benign prostatic hyperplasia (BPH) [26]. In 2001 Sedelaar *et al*. correlated the histologically determined MVD in radical prostatectomy specimens with three-dimensional (3D) contrast-enhanced power Doppler [27]. On average, the areas with increased enhancement had a 1.93 times higher MVD than unenhanced areas, and all enhancing areas contained prostate carcinoma. Only small satellite lesions (1–2 mm) were not identified on CEUS. This study clearly demonstrated that the increased MVI as a result of prostate carcinoma could be visualized with CEUS (Figure 117.1), and therefore could open the doorway to targeted biopsies.

Targeted biopsies

To investigate the role of targeted biopsies, Frauscher *et al*. investigated 230 patients with a prostate-specific antigen (PSA) greater than 1.25 ng/mL and a free-to-total PSA less than 18% in whom both CEUS-guided and systematic biopsies were taken [28]. In the CEUS-guided biopsies no transition and central zone biopsies were taken; in the systematic biopsies these biopsies were taken. They found no statistically significant difference in the cancer detection rate for CEUS and systematic biopsies (56 of 69 vs 52 of 69); however, there was a significant difference when only the peripheral zone cancers were considered (56 of 62 versus 45 of 62). The Gleason scores of the carcinomas found on systemic biopsy were 4–6, while the scores of the carcinomas found on CEUS biopsy alone were 6–9. This indicates that CEUS biopsies may detect more clinically significant tumors than systematic biopsies. In this study, CEUS and systemic biopsies differed significantly in the number of biopsies needed to detect cancer. Of the 2300 systemic biopsies, 123 showed cancer, while 118 of the 1139 CEUS biopsies showed cancer (positive predictive values of 5.3% vs 10.4%). The authors concluded that CEUS-targeted biopsies detected the same number of carcinomas, but with higher Gleason scores and with fewer biopsies.

In another study, Peltzer *et al*. investigated 380 patients with a PSA between 4 and10 ng/mL and a free-to-total PSA less than 18% with CEUS-targeted and systematic biopsies [29]. There was no significant difference between CEUS and systematic biopsies (104 vs 105 carcinomas of 143 carcinomas). CEUS and systematic biopsies combined were significantly more effective in

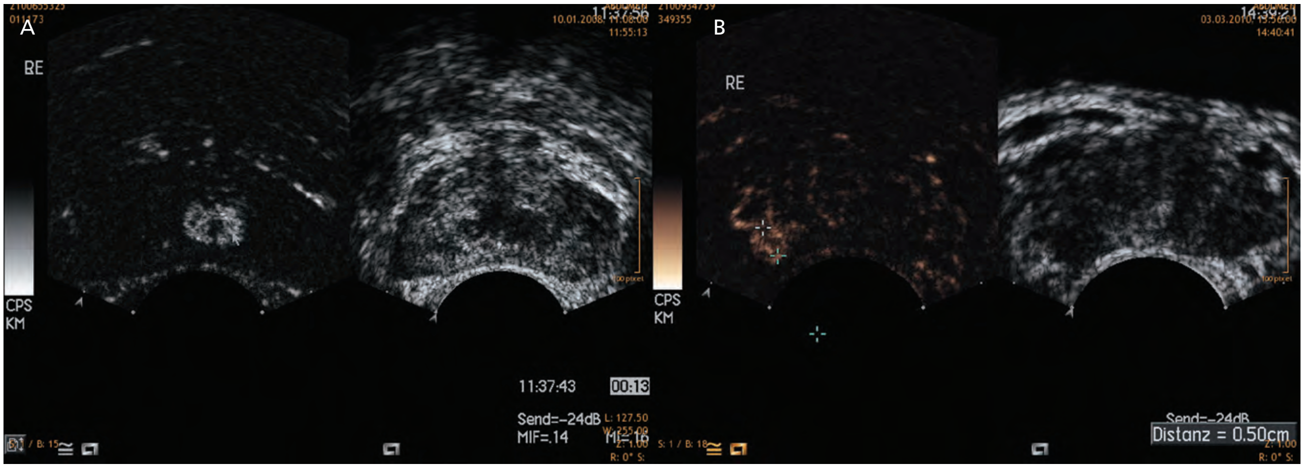

Figure 117.1 CEUS investigation of the prostate using the "cadence pulse sequence" technique. (A) An enhancing lesion is seen on the central left side and histology showed a Gleason 4 + 4 carcinoma. (B) A lesion is seen on the right side of the prostate, and histology showed a Gleason 4+3 carcinoma (reproduced by permission of Dr Ir. M. Misch, Eindhoven University of Technology).

detecting carcinoma than either modality alone. The authors concluded that for maximal detection a combination of systemic and CEUS-guided biopsies is preferred.

In 2009 Seitz *et al*. published data on CEUS in correlation with histologic specimens [30]. They included 30 patients who were scheduled for radical prostatectomy due to biopsy-proven prostate carcinoma and five patients who were scheduled for radical cystoprostatectomy due to muscle-invasive bladder carcinoma. On histologic evaluation one patient who underwent a cystoprostatectomy also showed prostate carcinoma. All patients underwent ultrasound and CEUS imaging before surgery, and afterwards the ultrasound and CEUS procedures were correlated with the histologic findings. Ultrasound identified 14 of the 31 foci and CEUS identified 22 of the 31 foci. On a patient basis there was no statistical significant association between ultrasound or CEUS and histology, but CEUS was significantly better than ultrasound in detecting carcinoma and the CEUS-enhancing tumors were significantly larger than the nonenhancing tumors. Of the foci found on CEUS, 77% were the index tumor, and of the foci found on CEUS, 86.4% were staged correctly. They concluded that CEUS correlated with histologic specimens on staging and the identification of the index tumor.

In summary, CEUS is a promising diagnostic tool for prostate carcinoma: it detects cancer as well as systemic biopsies with fewer biopsies needed, and the detected cancers are of higher Gleason score. When CEUS is compared with histologic specimens after radical prostatectomy, it frequently detects the index tumor and this tumor is mostly staged correctly. However, most CEUS studies in the diagnosis of prostate carcinoma involve relatively small populations and are single-center studies. Prospective multicenter trials are needed to confirm these results.

Use in focal therapy

CEUS can be used to guide and monitor focal therapy. Sedelaar *et al*. used CEUS to investigate the effectiveness of high-intensity focused ultrasound (HIFU) in the treatment of prostate carcinoma [31]. In this study, CEUS was compared with whole-mount histology specimens from patients who underwent a radical prostatectomy 1–2 weeks after HIFU treatment for a T1 or T2 prostate carcinoma. Overall a strong correlation of 0.98 between CEUS and pathology volumes of the lesion was found.

Atri *et al*. performed CEUS in 12 patients during interstitial laser therapy of the prostate [32]. After 1 week an MRI was performed to measure the size of the ablated prostate tissue. This measurement was then correlated with the CEUS measurement. The measured lesion sizes were identical on CEUS and MRI.

Eckersley *et al*. conducted CEUS in patients with prostate carcinoma before and during antiandrogen therapy and they compared the changes in PSA level with CEUS enhancement [33]. Within 1 week the decrease in vascular enhancement was similar to the decrease in the PSA level and this continued until 6 weeks after the start of the treatment. In four patients there was a discrepancy between the decrease in PSA level and the enhancement; the two patients with the most marked discrepancy relapsed after 6 months.

The earlier mentioned studies demonstrate that CEUS can be a potential imaging modality for the monitoring and follow-up of focal therapies in patients with local

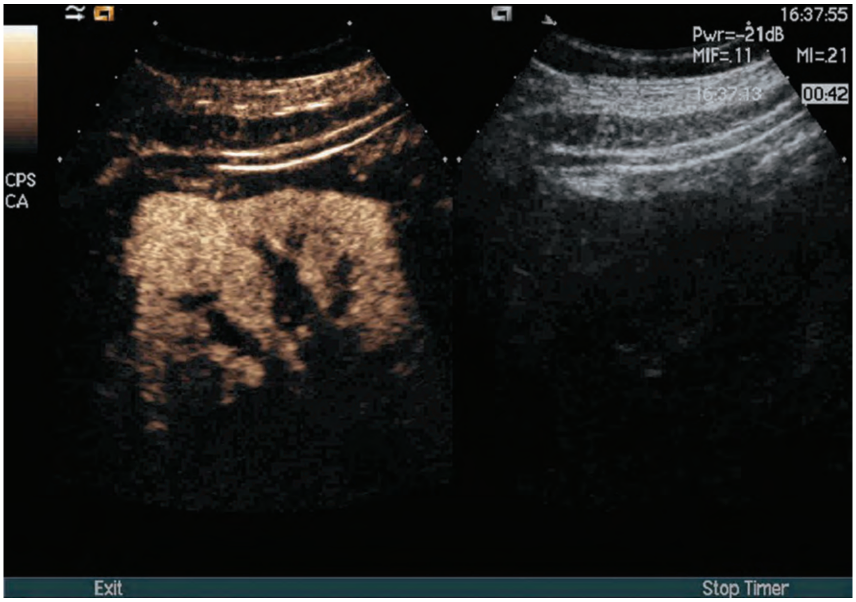

Figure 117.2 CEUS investigation of a kidney tumor. On the left side an enhancing lesion is seen.

prostate cancer. However, focal prostate cancer therapy is not yet a standard procedure because of the lack of clinical data needed to prove that proper visualization of cancer is possible.

Contrast-enhanced ultrasound in renal masses

The more frequent use of cross-sectional imaging has resulted in an increase in incidentally found renal masses. Renal masses are divided into cystic and solid masses, and cystic masses can be simple or complex. Approximately 10% of renal cell carcinomas present as complex renal cysts, but not all complex cysts are renal cell carcinomas [34–36].

Ultrasound imaging cannot differentiate perfectly between complex cysts that need surgery and those that can be observed. The enhancement characteristics of the cyst are a main feature on which this decision is made, and in most cases a contrast CT is used to image these characteristics. When a contrast CT is not possible, a contrast MRI can be used. The Bosniak classification is mainly used to characterize renal cysts [26, 27] (see Table 81.1).

CEUS can also be used to investigate enhancement characteristics, and in 2004 Thorelius used this technique for various organs [37]. In the kidney he noted that CEUS was highly sensitive in the characterization of nonvascular lesions (cysts, infraction, laceration).

Diagnosis of renal masses

The use of CEUS in the diagnostic evaluation of renal masses was described by Wink *et al*. in 2007 [38]. They performed CEUS in 18 patients with 20 masses and, if available, this was compared with the histology of the masses. Of the 13 masses for which histology was available, 12 showed a malignancy. Of the other seven masses, four were classified as Bosniak I or II(F) cysts; two as angiomyolipomas and one was suspicious for renal cell carcinoma. CEUS classified all the masses correctly and the authors concluded that CEUS is a promising technique for evaluating renal masses. Figure 117.2 shows an example of CEUS of a renal tumor.

Ascenti *et al*. used the Bosniak classification to compare CEUS with contrast CT in the classification of renal cysts [36]. They included 40 patients with one or more cysts of Bosniak II or higher and found a complete concordance between CEUS and CT in discriminating between nonsurgical and surgical cysts. Furthermore, CEUS identified 14 cysts with vascularization and CT 10 such cysts, and the general conclusion was that there was a high concordance between CT and CEUS.

Quaia *et al*. investigated 26 patients with renal masses, comparing CEUS with histology or CT [39]. Of the 26 masses found, 19 were solid renal masses: 11 solid renal cell carcinomas, seven angiomyolipomas, and one embryonal metanephric adenoma. They found that CEUS was able to differentiate as well as CT between solid renal cell carcinoma and angiomyolipoma.

A peritumoral pseudocapule is associated with a low-risk tumor, and the gold standard for its identification is currently MRI [40, 41]. Ascenti *et al*. investigated the capability of CEUS to diagnose the peritumoral pseudocapsule in 32 patients with 40 renal masses, of which 26 were renal cell carcinoma [42]. On histologic examination of the renal cell carcinomas in 14 of the cases, a pseudocapsule was present. Conventional ultrasound detected this in three cases with a sensitivity of 21%, while CEUS detected this in 12 cases with a sensitivity of 87.5%. Ascenti *et al*. concluded that CEUS can compete with MRI in the detection of a peritumoral pseudocapsule.

Use in ablative therapies

Because of the increasing incidence of small renal masses, of which a significant number are benign, more and more nephron-sparing treatment modalities have been introduced [34, 42, 43]. Along with partial nephrectomy, ablative treatments, including cryoablation and radiofrequency ablation (RFA), can be used, and CEUS could play a role in monitoring these treatments and also during follow-up, by visualizing the resulting perfusion defects.

To our knowledge, the first description of CEUS and RFA was in 2005 in two series in pigs [44, 45]. CEUS was performed after RFA, and the identified lesions were measured and compared with the histologic measurements after removal of the kidneys. The study of Johnson *et al*. found an average difference between CEUS and histologic measurements of 0.15 cm (length), 0.26 cm (height), and 0.19 cm (width) [44]. In the study by Slabaugh *et al.*, the average difference between CEUS and histologic measurements was 0.238 cm (length), 0.422 cm (height), 0.090 cm (width), and 0.195 cm^3 (volume) [45]. Both studies concluded that CEUS can visualize RFA defects with great accuracy.

Meloni *et al*. compared CEUS with contrast-enhanced CT or MRI after RFA in 27 patients with 28 tumors. Of these tumors 27 had a hypervascular pattern and one a hypovascular pattern at baseline imaging [46]. The concordance between CEUS and CT or MRI findings after RFA was 100% for the hypervascular tumors; the one case of hypovascular tumor progression was missed on CEUS. The sensitivity, specificity, and overall accuracy of CEUS were 96.6%, 100%, and 98.1%. They concluded that CEUS is a good alternative imaging technique for follow-up after RFA.

Wink *et al*. and Zhu *et al.* have described follow-up of cryoablation with CEUS [47–49]. Zhu *et al*. performed CEUS and CT or MRI in three patients before and after cryoablation. The CEUS images demonstrated the same enhancement patterns as CT or MRI, but CEUS better visualized the arterial feeding vessels. The feasibility study by Wink *et al*. used CEUS after cryoablation of renal tumors. They found that within 5 weeks after cryoablation the perfusion defect was larger than the initial tumor, and in one patient after 1.5 years the lesion was no longer visible. These studies suggest that CEUS may be a sensitive imaging technique for follow-up after cryoablation. An example of CEUS after cryoablation is shown in Figure 117.3.

Especially for ablative treatment modalities, CEUS seems to be a potential alternative to contrast CT or MRI. The absence of perfusion can be visualized with a very high sensitivity. Again, prospective multicenter trials are needed to determine the additional clinical value of this technique.

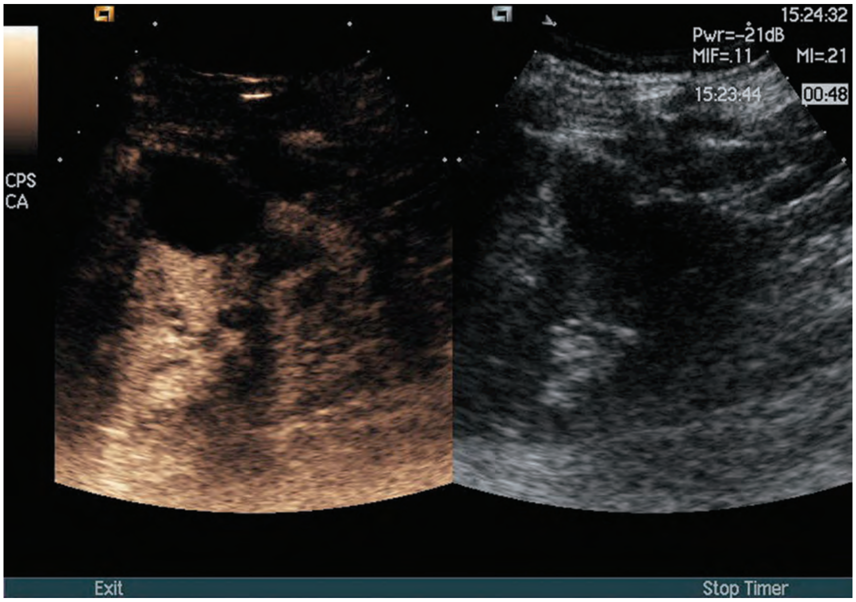

Figure 117.3 CEUS image of a kidney after cyroablation. A clear avascular zone is visible in the location where the cryoablation was performed.

Future developments

Quantification

In general, the described CEUS characteristics are the subjective determination of perfusion features by investigators, and may be subject to bias between centers and investigators. Quantification and calculation of well-defined perfusion parameters could make CEUS a more objective and reliable technique in the hands of novice users also.

A study by Goossen *et al*. indicated that the minimal time to peak enhancement was the most predictive factor to determine the most affected side with malignancy in patients with proven prostate carcinoma [50]. Van Moerkerk *et al*. stated that in 65% of the cases, computerized localization could discriminate between malignant and benign disease [51]. In both studies the CEUS quantification techniques were compared with the histology of radical prostatectomy specimens. Currently, new quantification techniques are under development that focus on the visualization of prostate cancer, and these may become useful future targeted biopsy guiding techniques [52]. An example such a quantification technique is shown in Figure 117.4.

Targeted microbubbles

Molecular imaging with targeted microbubbles has been tested in animal models [44, 45]. The bubbles used in these experiments have additional adhesion molecules built into their shells. Due to the binding of these adhesion molecules to receptors such as that for vascular endothelial growth factor (VEGF), which are over expressed in malignant tissue, sensitive imaging of malignancy becomes possible.

Wilmann *et al*. used mouse cell cultures for an *in vitro* study and tumor-bearing mice for an *in vivo* study of a VEGF-targeted bubble [53]. They compared a control contrast agent with targeted bubbles in cancer and non-cancer cells. In the *in vitro* study, significantly more targeted bubbles adhered to the cancer cells compared to the regular contrast agent (2.1 targeted bubbles/cell vs 0.1–0.01 control bubbles/cell), and significantly more targeted bubbles adhered to the cancer cells then to the noncancer cells. In the *in vivo* study the targeted bubbles showed significantly higher contrast enhancement than the control bubbles. In a blind experiment Lyshchik *et al*. compared CEUS using a VEGF-targeted bubble with a control bubble agent in tumor-bearing mice [54]. The targeted bubbles showed a statistically significantly higher enhancement then the control bubbles.

A new targeted contrast agent, referred to as BR55, was introduced by Bracco Imaging SpA (Milan, Italy), and has demonstrated increased enhancement of human tumor cells in a rat model [55]. BR55 is specially designed for use in humans, and therefore we can expect that these ultrasound molecular imaging techniques will shortly be available for use in humans.

As well as adding adhesive molecules to the shell, it is possible to add other molecules to the shell or the inside of the bubbles. By loading bubbles with drugs and using high-output ultrasound to destroy the bubbles, local drug delivery is possible. *In vitro* and *in vivo* experiments show that this is feasible. In 1997 Bao *et al*. used hamster cells to transfect DNA and fluorescent dextran into the cells using ultrasound with and without contrast [56]. Cells exposed to the contrast contained the DNA and fluorescent dextran, while those that were not exposed to the contrast did not. Haag *et al*. used ultrasound with a contrast agent to asses if a DNA particle could be transfected into human prostate

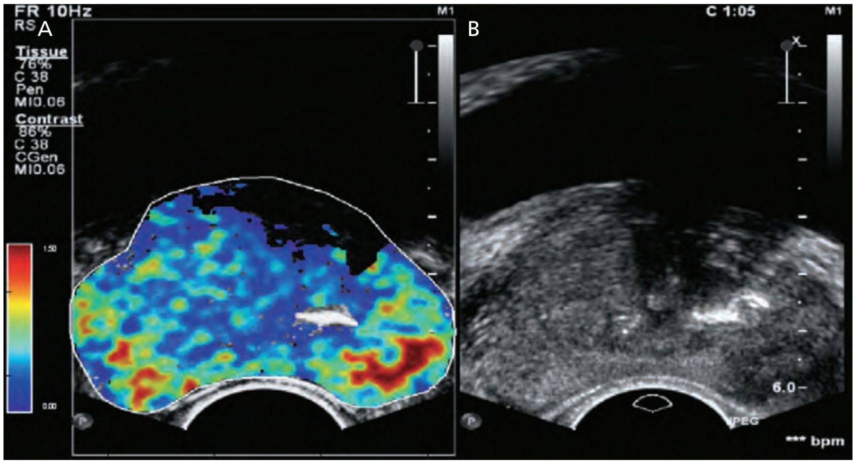

Figure 117.4 Quantification of CEUS with the technique "diffusion modeling/analysis.". (A) CEUS with an overlay of the quantification results. The red areas are predicted to have a high chance of being malignant. (B) Normal CEUS image (both images reproduced by permission of Dr Ir. M. Misch, Eindhoven University of Technology).

carcinoma cells [57]. Analysis of the cells revealed that 49% of the cells contained the inserted DNA particles. This group then used ultrasound with a contrast agent intratumorally or intravenously to transfect DNA into mice with prostate carcinoma. At 24 h after the ultrasound, the mice were sacrificed and the tumors were examined for the transfection of the DNA. Again, the tumor cells contained the transfected DNA, proving that *in vivo* DNA delivery though the use of ultrasound is possible.

The use of bubbles and ultrasound, and the bubble destruction process, have the additional benefit of higher uptake as the added molecules more easily cross the cell membrane [58].

Fusion imaging

CEUS technology has improved over recent years, and has become a technique by which tissue perfusion can be imaged in detail. New MRI developments, particularly for prostate cancer detection and localization, also show promising results in centers of expertise. Therefore, the fusion of recorded MRI studies and realtime CEUS could be an option to combine the "best" of both techniques. In the same way, CT and ultrasound or CEUS can be combined. In 2008 Ukimura *et al*. used fusion imaging to guide RFA treatment of renal cell carcinoma [59]. They found that fusion imaging allowed excellent anatomic visualization and a precise direction of RFA. In 2008 Xu *et al*. explored the use of fusion imaging in the diagnosis of prostate carcinoma [60]. They used previously recorded MRI images fused with real-time TRUS of the prostate to guide biopsies in 20 patients, and concluded that the fusion of these images provides clinically acceptable accuracy.

Conclusions

In centers of expertise, CEUS has become a perfusion imaging technique that shows promising results in the diagnosis and treatment of prostate and kidney cancer. The available results for monitoring and follow-up of focal (ablative) treatment modalities are also very encouraging. Therefore, an urgent need exists for larger prospective and multicenter studies that should provide the final evidence that CEUS has an additional clinical value.

CEUS is a still under development, but with the future introduction of targeted molecular imaging, it may play an even more significant role in the diagnosis and treatment of urologic malignancies. Fusion of different imaging techniques is under development, and it is expected that these techniques will allow even more accurate imaging of malignancies.

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CHAPTER 118

Endorectal MRI: Use in Prostate Cancer

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Introduction

Prostate cancer is the commonest nondermatologic cancer in men in the Western world [1]. Autopsy studies have shown that approximately 30–50% of men worldwide harbor latent prostate cancer by their 50th birthday and over 80% of men have cancer by their 80th year of life [2]. Although many with prostate cancer die from other causes, it is still the second leading cause of cancer death in men in the US after lung cancer, with 28 600 deaths in 2008 [3]. As its prevalence increases along with the increasing life-expectancy in men, prostate cancer is likely to become an even more critical healthcare issue in the future.

In the 1960s, digital rectal examination (DRE) was the mainstay of prostate cancer diagnosis. The DRE cannot diagnose microscopic cancers and is best at identifying larger cancers that have often spread beyond the confines of the gland. It is also not a very specific test, often being positive with a number of benign diagnoses (e.g. prostatitis, benign prostatic enlargement). In the late 1980s, the prostate-specific antigen (PSA) assay was developed. PSA cannot be used as an absolute diagnostic tool for prostate cancer as its levels can be elevated in various other pathologies, such as benign prostate enlargement (BPE), prostatitis, and prostatic infarct [4–6]. Even when DRE and PSA are combined, the sensitivity and specificity for diagnosing prostate cancer remain low (the exact values depend on the PSA threshold level chosen). Investigators have thus attempted to use other PSA characteristics, such as PSA velocity, PSA density, and free-to-total PSA ratios, none of which has reached widespread clinical uptake due to their failure to improve the accuracy of PSA to a sufficient degree; the ROC AUC (receiver operator curve area under the curve) remains less than 85%.

Given the significant limitations of DRE and PSA to diagnose prostate cancer, imaging modalities have been evaluated. Transrectal ultrasound (TRUS) is the most commonly used and readily available modality. However, it provides little advantage over DRE and PSA, with a positive predictive value (PPV) of 52.7%, negative predictive value (NPV) of 72%, and accuracy (ROC AUC) of 67% [7]. The value of TRUS in the local staging of a tumor is also poor, and is no more accurate than DRE for the purpose of detecting local tumor extension according to a multi-institutional study [8]. Hence, in current practice, TRUS is limited to guidance of prostatic biopsies.

Magnetic resonance imaging (MRI) was developed by Mansfield and Lauterbur, who won the Nobel Prize in Physiology or Medicine in 2003 for their pioneering work. MRI is based on the principle of nuclear magnetic resonance, which won Bloch and Purcell the Nobel Prize in Physics in 1952. It has widespread applications in human radiology, including prostate cancer imaging. Endorectal coils are used either alone or in combination with phased-array surface coils. They have enabled increasingly accurate evaluation of extraprostatic extension (EPE) and seminal vesicle involvement (SVI) of prostate cancer [9–11]. Today, endorectal MRI (eMRI) has applications in diagnosis, staging, pretreatment planning, and follow-up of prostate cancer. Recently, the addition of functional sequences (perfusion imaging,

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diffusion imaging, and spectroscopy) to the morphologic T2-weighted imaging has enhanced the ability of MRI to differentiate between tumoral and normal tissue [12–19]. Endorectal coils are preferentially used in obtaining these functional sequences as they better receive signals close to the prostate, and thus a higher signal-to-noise ratio (SNR) can be obtained without sacrificing an already low spatial resolution.

Protocol for endorectal imaging

MRI is a noninvasive modality that uses magnetic and radio waves together with a computer to create cross-sectional images of various parts of the body. Food and fluids are restricted from midnight the night before until after the procedure is complete. For prostate imaging, the bowel is prepared using an enema. Before the procedure, per rectum examination is performed to assess the area for safe probe insertion. The endorectal coil or balloon coil has a flexible shaft with a small balloon at one end. Once inserted, the balloon is filled with air until it comes into contact with and conforms to the size and shape of the prostate. A shot of glucagon may be given to the patient to keep the bowels from moving. The patient is placed in the supine position and kept still while the MR images are taken.

Role of endorectal MRI in early diagnosis of prostate cancer and in patients with a rising prostate-specific antigen

Early diagnosis of prostate cancer

In this era of PSA screening, patients with negative prostatic biopsies and a continually rising PSA are encountered more frequently [20]. Established strategies for managing such patients include a repeat biopsy scheme (10–12 cores), saturation/template biopsy (>12 cores), or continued PSA monitoring. None of these strategies is ideal; the first two are invasive and may still miss significant cancer, while the third does not deal with what steps to take if the PSA continues to rise. A noninvasive imaging modality would constitute a major breakthrough in prostate cancer diagnostics. eMRI shows promise in this area. Studies have shown that MRI in patients with one set of negative biopsies and a continuing rise in PSA levels is better than repeat TRUS biopsy [21, 22]. In a screening population of 92 patients, Comet-Batlle *et al*. have demonstrated 80% sensitivity, 76.1% specificity, 55.6% PPV, 91.1% NPV, and 77.2% accuracy for MRI, compared to 85% NPV of a negative octant biopsy for prostate cancer [23]. Cheikh *et al*. reported 82.6% sensitivity and 100% NPV of T2-weighted MRI when evaluating visible suspicious areas prior to repeat TRUS prostate biopsy [24]. An MRI showing "no evidence of disease" in a patient with a marginally raised PSA would seem to offer a similar level of reassurance as two sets of prostate biopsies that are reported as "no cancer detected" [23].

MRI-targeted prostate biopsy

Another approach for patients with negative biopsies and a continually raised PSA is to use MRI-targeted biopsy. In targeted biopsies the eMRI, done prior to the TRUS, is used to direct biopsies towards suspicious lesions. Targeting biopsies provides the advantage of detecting prostate cancer that might not have been detected by systematic sampling alone, particularly those outside the peripheral zone [21, 22, 25, 26]. In a study by Perrotti *et al*. in a cohort of 33 patients, MRI had 85.7% sensitivity, 65.5% specificity, 40% PPV, 94.4% NPV, and 69.7% accuracy. They found that a positive eMRI (moderate or high suspicion) indicated a 11.3-fold increased risk of positive biopsy [27]. In a similar study, Beyersdorff *et al*. found that targeting biopsies to suspicious areas on MRI led to a sensitivity of 83%, specificity of 62%, and PPV of 50% for detection of cancer [21].

Sciarra *et al.* in a prospective study on 180 men with prostate cancer assessed the role of magnetic resonance spectroscopy imaging (MRSI) and dynamic-contrast enhancement magnetic resonance (DCE-MRI) in targeting biopsies in patients with persistently elevated PSA levels with prior negative biopsy, and compared the results with those obtained with a second TRUS-guided biopsy [28]. On the repeat biopsy, prostate cancer was found in 22 of 90 men (24.4%) who had second TRUS-guided biopsy compared to 41 of 90 men (45.5%) ($P = .01$) who had MRSI–DCE-MRI targeted biopsy. MRSI had 92.3% sensitivity, 88.2% specificity, 85.7% PPV, 93.7% NPV, and 90% accuracy; DCE-MRI had 84.6% sensitivity, 82.3% specificity, 78.5% PPV, 87.5% NPV, and 83.3% accuracy; and the association MRSI plus DCE-MRI had 92.6% sensitivity, 88.8% specificity, 88.7% PPV, 92.7% NPV, and 90.7% accuracy for predicting prostate cancer detection. Therefore, the combination of MRSI and DCE-MRI has a higher potential to target biopsy to cancer foci in patients with a previously negative TRUS biopsy.

Although the results of this approach are encouraging, it also has certain limitations. Sometimes the lesions detected on MRI are not visible on ultrasound, making it difficult to target the biopsy to the site of the lesion on MRI. This causes false-negative results due to errors in guidance. The underlying problem is that biopsies cannot be taken in realtime under MR guidance, and it is difficult to precisely localize all MR-suspicious areas with TRUS.

Role of endorectal MRI in patients with clinically localized prostate cancer

Prostate cancer detection

A TRUS-guided prostate biopsy targets the peripheral zone of the prostate; thus, tumors in the anterior fibromuscular stroma, transition zone or apex are often missed. Also, only a small proportion of the peripheral zone itself is sampled by the TRUS-guided biopsy, and the overall NPV of the biopsy is 70–80% [29].

With eMRI, the detection of prostate cancer depends on the type of imaging sequence used. On T1-weighted images, the prostate demonstrates homogenous medium signal intensity. On T2-weighted MR images, prostate cancer is shown most commonly with decreased intensity within the high signal intensity normal peripheral zone. The ability of MRI to localize disease within the gland varies, with sensitivities from 37% to 96% in published studies; this variation is due to a number of factors: the criteria used to define the significant tumors, the method of analysis, and whether the reference standard was TRUS biopsy or whole-mount histology. The specificities range from 21% to 67% [30]; therefore, MRI has reasonable sensitivity but poor specificity for prostate cancer detection [21, 31, 32]. Furthermore, the accuracy of cancer detection also varies according to the size of the tumor, location of the tumor, and biopsy-associated changes, which can cause incorrect estimation of tumor presence and extent. It is notoriously difficult to distinguish biopsy-associated hemorrhage from tumors on T2-weighted images. Therefore, an interval of at least 6 weeks is generally recommended between prostate biopsy and MRI [33].

With the widespread introduction of PSA testing, there has been a shift towards detection of prostate cancer at an early stage of disease. Roethke *et al*. studied the tumor size-dependent detection rate of eMRI and found greater accuracy for detecting large and high Gleason score tumors, than for small and low-score tumors. Tumors smaller than 0.3 cm were not visualized on MRI (detection rate 0%); the detection rate for tumors between 0.5 and 1 cm was 13%, for tumors of 1–2 cm it was 45%, and for tumors of greater than 2 cm it was 89% [34]. The inability of MRI to detect tumors smaller than 0.5 cm is of uncertain value. Such small foci are often regarded as clinically insignificant and it is known that only the volume of the largest focus of cancer (the "index tumor") in men undergoing radical prostatectomy influences PSA failure, while small foci of less than 0.5 cm^3 seem to have little or no effect [35, 36]. However, these small foci may represent potential for clinical significance with increasing time. The problem is that the size of the tumor has not been shown to correlate well with need for treatment and thus, the rationale for active surveillance remains to be proven. However, a study by Shukla-Dave *et al*. in 220 men with localized, low-risk prostate cancer showed that models incorporating T2-weighted MRI with clinical and biopsy data performed significantly better than models without imaging data in identifying men with prostate cancer of less than 0.5 cm^3 cancer and Gleason score of 6 or less [37].

The specificity of MRI is decreased by its inability to distinguish between the low T2 signal intensity that is associated with tumors from other pathologies, such as prostatitis, postbiopsy hemorrhage or treatment changes [38].

MRI was initially thought to be less effective in the detection of prostate cancer in the transition zone. Recent studies, however, have shown that MRI has roughly equal accuracy throughout the prostate, and good sensitivity and specificity (75% and 87%, respectively) in detecting transition zone cancers as well [39]. Akin *et al*. suggested that indicators of transition zone cancer include homogenous low signal, lenticular shape, and invasion of the anterior fibromuscular stoma [39].

Prostate tumor burden

It is often found that pathologic staging, surgical margin status, histologic grade, and tumor volume are powerful predictors of individual prognosis and prostate cancer biology [40–42]. Tumor volume estimated from prostatectomy specimens correlates with the risk of failure after radical prostatectomy [43], and tumor volumes less than 0.5 cm^3 are considered to be insignificant [44]. Tumor volume measurement may therefore provide important information for therapy planning. Huge variation has been noted across various publications in measuring tumor volume using eMRI. Jager *et al*. reported poor correlation between tumor volumes determined from MR images and pathologic sections: the actual tumor volume was predicted within 25% of the pathologic tumor volume in only 30% of the cases. An overestimation was seen in 47% of cases and an underestimation in 23% of cases [45]. Ponchietti *et al*. found a good correlation ($r = 0.94$) between tumor volumes determined from eMRI and pathologic specimens; however, MRI tended to overestimate volumes of small tumors and underestimate volumes of large tumors despite efforts to reduce the possible sources of artifacts [46]. Kahn *et al*. showed an average of 40% discrepancy in measurement of tumor volume for unenhanced MRI [47]. Nakashima *et al*. used tumor diameter as the measure of tumor volume and found that maximum tumor diameter on eMRI correlated significantly with that shown by histologic examination, especially for tumors greater than 1 cm in diameter, although it did not correlate significantly with the histologic diameter of tumors of less than 1 cm [48]. Therefore, eMRI would be more useful to stratify patients with prostate cancer volumes of greater than 1 cm^3.

Local prostate cancer staging

Different classifications have been applied to stage prostate cancer, but only the TNM (tumor, node, and metastasis) system is widely used worldwide. The TNM staging system uses imaging to define presence and extent of prostate cancer. The goal of imaging technology is to differentiate between diseases confined to the gland (T1–T2) and locally invasive disease (T3). Further, in locally invasive disease it is important for therapeutic planning and prognostication to distinguish those tumors penetrating the prostate capsule but sparing the seminal vesicles (T3a) from those invading the seminal vesicles (T3b). Patients with organ-confined disease can be treated with radical prostatectomy or radiation therapy, whereas those with more advanced disease are treated with radiation therapy, hormonal therapy or a combination of these [49, 50].

DRE and PSA level assessment are not accurate in determining the local tumor stage, with underestimations as high as 40–60% [51]. Among the imaging techniques, TRUS can accurately detect locally advanced tumors but is not sensitive enough to detect the initial extraprostatic spread across the capsule or into the seminal vesicles in clinically confined lesions. The introduction of eMRI has dramatically improved the spatial resolution compared to the conventional phased-array body coil [52–55]. As a result, there has been a significant increase in the ability to correctly define tumor location and extent, enhancing the ability to tailor the treatment selection to ensure complete eradication of cancer while minimizing treatment-related morbidity.

Prostate cancer on eMRI can be diagnosed as intracapsular when the normal hyperintense prostatic tissue is seen between the tumor and the capsule or when there is a clear delineation of the capsule itself, despite the vicinity of the tumor. On the other hand, any bulging or irregularity in the contour of the gland, hypointense focal thickening of the capsule at the capsular margin or at the edges of the tumor, and retraction of the capsule adjacent to the tumor are highly suspicious signs for capsular penetration [56].

Staging accuracy

MRI is now considered by many to be the most exact imaging modality for staging prostate cancer, including capsular penetration, pelvic lymph nodes, and pelvic bone metastasis [57–59], invasion of neurovascular bundles (NVBs), and SVI [56, 60]. Precise analysis of all of these features is crucial for accurate treatment planning.

In a study examining the local staging accuracy of 3-T eMRI, Futterer *et al*. reported high accuracy levels of 94% and 81%, sensitivities of 88% and 50%, and specificities of 96% and 92%, for an experienced and a less experienced radiologist, respectively [61]. Although there has been a wide variation in the reported accuracy of prostate cancer staging by MRI, this has improved with increased reader experience, maturation of MRI technology (faster imaging sequences, more powerful gradient coils, and postprocessing image correction), and improved understanding of morphologic criteria to diagnose EPE and SVI.

Extraprostatic extension

EPE is suspected on eMRI in the presence of capsular penetration, bulging of the prostatic contour caused by the tumor, stranding in the periprostatic fatty tissue, tumor tissue in the extraprostatic tissue, asymmetry of the NVBs, and obliteration of the rectoprostatic angle. The presence of EPE is one of the most important prognostic factors in patients with prostate cancer and has been well correlated with treatment failure after radical prostatectomy, particularly if a nerve-sparing surgical technique is used. Pretreatment awareness of the presence and extent of EPE is important for treatment selection and management planning.

Yu *et al*. studied 77 patients with stage pT2 and pT3 prostate cancer and reported obliteration of the rectoprostatic angle and asymmetry of the NVB as the MRI imaging features most indicative of EPE [62]. Furthermore, radiologist experience was determined to be an important factor in interpreting MRIs and contributed to interobserver variability. Wang *et al*., in their study on 344 patients, found that eMRI outperformed biopsy Gleason score, clinical stage, preoperative PSA, greatest percentage of cancer and percentage of cancer-positive core specimens in all core biopsy specimens, and the presence of perineural invasion in the pretreatment evaluation for presence of EPE, with a sensitivity of 42.2% and specificity of 95.4% [63].

Seminal vesicle involvement

MRI is instrumental in identification of SVI, because of its excellent soft tissue resolution. SVI on MRI appears as low signal intensity within the seminal vesicle and/or lack of preservation of normal seminal vesicle architecture. These features along with the presence of tumor at the base of the prostate and EPE are highly predictive for the presence of SVI [64].

Sella *et al*. reported that MRI, when interpreted by dedicated genitourinary radiologists experienced in prostate imaging, can accurately predict SVI [64, 65]. They compared the nomogram predictions for SVI with and without eMRI findings and proposed that an incremental value was added by eMRI with ROC AUC of 0.87 (87%) and 0.80 (80%), respectively ($P < .05$) [66].

Role of endorectal MRI in clinical decision-making

Preoperative decisions

The success of radical prostatectomy is measured by both oncologic and functional outcomes, including postoperative rates of urinary continence and return of erectile function [67]. Approximately 50% of men with a positive surgical margin (PSM) may have biochemical recurrence at 10 years after radical prostatectomy [68]. The risk of a PSM is influenced by the surgical approach, location and extent of disease (i.e. presence of EPE), with reported rates ranging from 6% to 41% in modern surgical series [40, 69–71]. EPE is a microscopic phenomenon; therefore, its presence and location is difficult to predict using both clinical and preoperative pathologic parameters alone. eMRI, due to its ability to spatially characterize the location and extent of disease, can significantly improve the predictive capabilities of clinical and pathologic parameters for the presence of EPE [63, 72]. The decision to preserve or resect the NVB responsible for erectile function is often difficult and is based upon preoperative clinical and pathologic characteristics, as well as intraoperative findings. MRI can provide surgeons with a better assessment of risk for EPE in the area of the NVB along the posterolateral aspect of the prostate. This allows for an opportunity to preoperatively alter the surgical approach to improve cancer control, while preserving periprostatic tissue important for recovery of urinary and sexual function. Hricak *et al*., in their series of 135 patients undergoing radical prostatectomy, found that by reviewing preoperative endorectal MR images surgeons were more accurately able to decide whether or not to preserve the NVB during surgery [73]. Patients were evaluated with MRI preoperatively by an experienced radiologist. Their findings were then compared to the surgeons' clinical judgment during surgery as well as to histopathologic findings. They found that when the surgeon decided to spare the NVB, MRI confirmed that decision in 84% of cases and this was correct 96% of the time. MRI results changed the surgical plan in 78% of high-risk patients (>75% risk of EPE on Partin tables) and was correct in 93% of cases. Recently, in another study, 75 patients with prostate cancer from 2004 to 2007 were evaluated with preoperative MRI, which showed a sensitivity of 92% and specificity of 100% for the detection of EPE/NVB involvement [74]. MRI findings favored NVB preservation in 67% of patients with a high clinical probability of EPE, and opposed NVB preservation in 33% of patients with low probability; these findings were correct 100% of the time. Therefore, eMRI is useful in predicting the absence of tumor in the area of the NVB in patients with low and intermediate risk.

Additionally, the ability of eMRI to visualize a large anterior transition zone or apical cancer allows for surgical modification of where the dorsal vein complex is divided and how to dissect the prostatic apex in order to improve local cancer control in areas at risk for EPE as well as to reduce PSM rates. Further, the presence of prominent apical periprostatic veins on eMRI has been strongly associated with increased intraoperative blood loss and may assist in predicting men at risk for substantial intraoperative hemorrhage [75].

Focal therapy decisions

There are very few studies of MRIguided focal ablative modalities. The ability of MRI to accurately stage and characterize the disease may play a critical role in its utilization for delivering focal therapy. With additional development, MRI-guided focal therapy may become a viable option for the management of low-volume and low-risk prostate cancer. Lindner *et al*. showed the feasibility of image-guided laser ablation of small-volume prostate cancers in their initial experience with MRI-planned, ultrasound-guided photothermal focal therapy on 12 prostate cancer patients [76]. In a further study, they performed MRI-planned, ultrasound-guided focal laser therapy (FLT) followed by radical prostatectomy and found no viable tumor in whole-mount histopathologic examination of the ablated area [77]. Raz *et al*. used outpatient inbore MRI-guided focal laser ablation for low-risk prostate cancer. In their trial, MRI-guided FLT allowed for visualization of the tumor, realtime guidance of the thermal device to the target, and monitoring and control of the zone of ablation and surrounding tissue during treatment. MRI allows the immediate confirmation of the success of the treatment and, if necessary, immediate repeat therapy [78]. Although further trials will be necessary to define the safety and oncologic efficacy of this outpatient procedure, its refinement may result in an inexpensive, minimally invasive alternative to current active therapies.

Role of endorectal MRI in patients with biochemical recurrence

Recently, eMRI has proven capable of detecting local recurrence in many patients with a rising PSA but no palpable tumor on DRE. Silverman and Krebs demonstrated the potential of eMRI in the evaluation of local recurrence following prostatectomy with excellent sensitivity (100%; 95% CI 89–100%) and specificity (100%); 95% CI 69–100%) [79]. A study by Sella *et al*. confirmed the high efficacy of MRI (sensitivity for detecting a recurrence was 95% and specificity 100%). In patients with recurrent cancer after radiation therapy, MRI has shown reasonable accuracy in tumor detection, including the detection of EPE and SVI [80].

MRI has been shown to be superior to TRUS in detecting local recurrences of prostate cancer. In addition to detecting local recurrence in the perianastomotic and retrovesical regions (the sites also well identified on TRUS) [81], it can also detect recurrences occurring elsewhere in the pelvis, such as at the site of retained seminal vesicles or at the lateral and anterior surgical margins, which together account for 30% of local cancer recurrences [82]. MRI, therefore, has the potential to direct a transrectal biopsy to these sites and thus may lead to a better diagnostic yield than TRUS. An additional benefit of MRI over TRUS is the ability to concomitantly evaluate pelvic lymph nodes and osseous structures, thus detecting all sites of pelvic relapse in a single examination.

Recent advances in imaging using endorectal MRI

MRI-guided biopsies

MRI provides superior anatomic detail compared to computed tomography (CT) and TRUS; hence, a combination of tissue biopsy and MRI is a more sensitive tissue sampling tool. Stereotactic placement of the needle under MRI guidance helps to target the suspected tumor site, and allows volumetric verification and documentation of the actual biopsy location, which can be used for future intervention [83]. D'Amico *et al*. were the first to successfully perform MRI-guided prostate biopsy using the transperineal approach; they did this in a patient who had previously undergone proctocolectomy [84]. Subsequently, Susil *et al*. developed a transrectal system in a canine model, which enabled precise MRI guidance, accurate targeting, and intervention monitoring [85]. Beyersdorff et al. performed MRI-guided prostate biopsies in 12 patients in a closed 1.5-T MRI unit [86]. They used a biopsy device that was compatible with MR and consisted of a needle guide that could be visualized under MRI and manipulated mechanically from outside the MRI unit. They showed that the device enabled the MRI-guided core-needle biopsy of areas suspicious for cancer. More recently, Susil *et al*. demonstrated the feasibility of a system that provides transrectal needle access to the prostate during direct imaging with a 1.5-T MRI unit for prostate biopsy [87].

MRI-guided prostate biopsy seems to be a promising technology, especially in individuals with previous negative TRUS-guided biopsies. It not only enables direct visualization during diagnostic and therapeutic procedures, but can also provide direct temperature monitoring (during MR thermometry) to ensure adequate treatment [88, 89]. The main drawback of MRI-guided biopsy is the magnetic environment, which makes interventional procedures complex, leading to prolonged occupancy of the MR suite, increased costs, and patient discomfort because of procedural positioning. Another issue with MRI-guided biopsy is the need for motion correction during the biopsy procedure.

Magnetic resonance spectroscopy

MRSI increases the sensitivity and specificity of MRI by analyzing the metabolic profile of discrete voxels within the prostate [16, 88]. Intraprostatic tumor growth is associated with increased cell membrane turnover and increased cell proliferation, which leads to an increase in cellular choline and a decrease in citrate levels [90]. Wefer *et al*. compared MRSI and MRI and found that MRSI alone had a higher sensitivity (76%) than T2-weighted MRI alone (67%), but a lower specificity [38]. However, the accuracy in diagnosing prostate cancer is highest when anatomic information from MRI and metabolic information from MRSI are combined [16, 88]. Further, another study combining data from MRI/MRSI with clinical and pathologic data found the combined model to be superior to purely clinical models at predicting the probability of insignificant prostate cancer [37]. Recently, several studies have also analyzed the effects of adding data from MRI/MRSI to conventional staging nomograms. In a study on 229 patients who underwent MRI and 383 who underwent combined MRI/MRSI prior to radical prostatectomy, the radiologic findings contributed significant value to the standard nomogram for predicting prostate-confined disease [72].

MRSI has potential as a noninvasive method of assessing tumor aggressiveness and its sensitivity is higher for detecting high-grade tumors. Zakian *et al*. studied the relationship between Gleason score as a measure of tumor aggressiveness and MRSI volumetric and metabolic data, and found that the ratio of creatinine plus choline to citrate positively correlates with prostate cancer and can predict the aggressiveness of the tumor [91]. They also found that MRSI detected only 44% of Gleason score 3 + 3 tumors, compared to 90% of Gleason score greater than 7 cancers.

MRSI can detect transition zone tumors in about 80% of cases; this is significantly higher than with T2-weighted MRI [39]. Coakley *et al*. found an improved accuracy in tumor volume measurements when combination of MRSI/MRI was used [92]. Yu *et al*. also demonstrated that use of spectroscopic imaging decreases interobserver variability and, for less experienced radiologists, improves the detection of EPE [58].

MRSI can also supplement biopsies as a method of detecting both primary and recurrent cancers [30, 38] and to guide biopsies [93, 94]. Due to its higher sensitivity in detecting cancer compared to sextant biopsies, especially when a tumor is localized at the apex where biopsies may not sample [38], it can potentially be used to follow-up patients who have undergone ablative therapy. Parivar *et al*., in their study on 25 patients who had cryotherapy for prostate cancer, found that MRSI detected all recurrent foci of tumor [95]. Another study of nine patients with recurrent prostate cancer after radiation therapy found that MRSI and MRI was both superior to biopsy at detecting recurrent disease, with sensitivities of 77% and 68%, respectively [93]. However, they also reported a significantly lower specificity of MRSI (78%) compared to conventional MRI, DRE, or sextant biopsy, which was attributed to postradiation metabolic changes in the normal prostate. Therefore, the authors suggested that MRSI may be used to supplement other techniques to detect recurrent cancer or guide biopsies or treatment by localizing tumor [93].

Dynamic contrast-enhanced MRI

Jager *et al.* first demonstrated significant improvement in prostate cancer detection with DCE-MRI in 1997. Detection increased from 57% with T2-weighted MRI alone to 73% when combined with DCE-MRI. Specificity remained fairly high at 80% [96]. Schlemmer *et al.* demonstrated a sensitivity improvement from 79% to 89% in the peripheral zone [97]. A maintained high sensitivity was further confirmed in studies by Ito *et al.* [98] and Hara *et al.* [99].

The DCE profile of a given imaging voxel (3D pixel) over time offers important information about blood flow, capillary leakage, and other physiologic processes that occur in cancerous lesions. Gadolinium-based contrast agents are used because they are diffusible (passing through capillaries) and are nonlipophilic (allowing them to remain extracellular). With recent advances in faster imaging, postprocessing hardware, and mathematical modeling, DCE-MRI has shown significant expansion in the field of prostate imaging.

DCE-MRI has promising application in the prostate and in various other organs/tissues as well, because it can detect angiogenesis (neovascularization) and microvascular properties in glandular tissues. During the cancerous process, not only is there angiogenesis, but the structure and orderly organization of these blood vessel networks are also disrupted. The newly formed blood vessels have leaky endothelia and disrupted barriers, which result in increased permeability of vessels and extravasation of the contrast. DCE occurs on a microvascular level and MRI can visualize the compartmentalization of tissue into the vascular and extravascular–extracellular space (EES). DCE-MRI allows measurement of contrast diffusion across the vascular endothelium and capillary boundaries, enabling extraction of multiple physiologic parameters that are essential for better detection, localization, and characterization of prostate malignancy.

During DCE-MRI, T1-weighted sequences are repeated before, during, and after the injection of the contrast, for a specified period of time. Most commonly, the injection of low molecular weight gadolinium is followed by serial T1-weighted three-dimensional (3D) MR image acquisitions. The temporal resolution of the dynamic acquisition for prostate imaging varies widely from 1–2 s up to 95 s, being mostly in the range of 2–20 s/dynamic phase.

Cancers can demonstrate a large, early enhancement followed by a quick washout time–intensity curve. Although this pattern can be predictive of prostate cancer, it is not reliable enough for accurate, reliable diagnosis. This qualitative assessment of contrast enhancement time–intensity curves is often used with DCE-MRI, but has limitations in terms of generalization across protocols, scanners, and other factors contributing to the MR signal intensity, including contrast agent type and dose, and MRI sequence type and settings. Hence, there is a need for quantitative modeling and assessment to provide a consistent, standardized image acquisition technique and interpretive diagnostic methodology.

The most accepted quantitative approach is the pharmacokinetic (PK) model that converts enhancements (signal intensity changes) seen on the MR images into contrast concentrations, then calculates physiologic parameters, on a voxel-by-voxel basis, which provides standardized and reliable information about tumor physiology. As discussed by Alonzi *et al*., the PK model describes the contrast exchange between the following four main compartments: blood plasma, whole-body extracellular space, tumor leakage space, and contrast elimination from blood through kidneys [100]. In clinical practice, diagnostic interpretation using a quantitative method such as PK modeling is performed using computer-assisted diagnosis (CAD) software that performs the image analysis postprocessing.

Diffusion-weighted MRI

Diffusion-weighted imaging (DWI) is a method of obtaining molecular and cellular information regarding the movement and functional environment of water in the prostate tissue. By measuring the microdiffusion of water in the intra- and extra-cellular spaces, DWI can calculate an apparent diffusion coefficient, which reflects compartmental shifts in water, membrane permeability, and cellular density, all of which may be altered in cancerous tissue [101]. Cancerous prostate tissue has an increased cellularity, which lowers the apparent diffusion coefficient compared to the normal prostate tissue, both in the peripheral zone [102] and in the transition zone [103], in turn causing a reduction in the flow or diffusion of water [102, 103]. Several studies have analyzed the value of adding DWI to T2-weighted MRI and MRSI, and have found increased sensitivity (54%–98%) and specificity (58%–100%) [17, 101, 104]. Kim *et al*. proposed that combined DWI/T2-weighted imaging is more sensitive for predicting recurrent cancer after radiation therapy compared to the conventional T2-weighted imaging alone [105]. More recently, Park *et al*. reported that DWI is useful in the evaluation of patients with persistently elevated PSA values but negative prostate biopsies, as it is more sensitive than T2-weighted MRI in localizing lesions [106]. DWI has also been found to increase the accuracy of peripheral zone tumor volume assessment [107]. The major drawback, of this technology, however, is a substantial overlap of apparent diffusion coefficient (ADC) values between malignant and normal prostatic tissue and a marginal SNR. At present, modern 3-T MRI systems are under investigation for their utility in increasing SNRs for DWI [105]. Early studies with this technology report a high sensitivity (94%) and specificity (91%) in the peripheral zone, and a similarly high sensitivity (90%) and specificity (84%) in the transition zone [108]. Although, preliminary studies are promising, future research will further elucidate the role of DWI in the diagnosis and staging of prostate cancer.

Lymphotrophic nanoparticle MRI

Another upcoming MRI-based technology is the use of lymphotropic superparamagnetic nanoparticles as a contrast agent for detection of small and otherwise undetectable nodal metastases. These nanoparticles are injected intravenously and are taken up by macrophages in normal lymph nodes. This creates a contrast between benign nodes and cancerous nodes where the macrophages have been replaced by tumor cells [109]. Unlike conventional radiologic staging, this technology does not rely on the size or shape of the lymph node and is therefore more accurate in detecting metastases. It has proven to be effective in several other cancers [109] and investigations into its potential use in prostate cancer are ongoing. Harisinghani *et al*. evaluated 80 patients who had lymphotropic nanoparticle MRI (LNMRI) prior to either pelvic lymphadenectomy or detection of metastasis on CT. They found that LNMRI can detect metastases in small lymph nodes that would be considered benign on CT or unenhanced MRI, and that there were metastatic nodes outside of the classical field of lymph node dissection in a significant number of patients [110]. They reported an increase in sensitivity of MRI from 45.4% to 100% with a specificity of 95.7%. Therefore, this technology may be of particular utility in patients who have a high risk of metastatic disease on the basis of standard staging nomograms and conventional MRI, both of which have high NPVs for detecting metastatic disease [111]. This technology is also useful for detecting recurrent cancer, as well as guiding targeted radiation therapy. In a recent study on 26 patients with recurrent prostate cancer who were candidates for salvage radiation therapy, LNMRI detected positive nodes in six patients, none of whom had enlarged nodes on axial imaging [112]. Further studies are needed before this promising technology enters in the clinical arena.

Endorectal MRI and future research

MRI/MRSI and prostate biopsy

The replacement of biopsy by MRI has not yet been advocated, but Wefer *et al*. proposed that it might be possible in some cases [38]. They compared the sensitivity of unenhanced MRI, spectroscopy, and sextant biopsy for localizing cancer to a specific sextant and found both imaging techniques more sensitive than biopsy in the detection of cancer. They concluded that "MR spectroscopic imaging is significantly better than biopsy, when high sensitivity is required." These finding were also recently confirmed by another study using T2 sequences and spectroscopy [31]. Therefore, MRI will be useful in the follow-up of focally or incompletely treated glands. Initial studies also suggest that MRI may be a superior modality for planning focal therapy. Once the diagnosis of cancer has been made, treatment might be directed at all suspicious areas on MRI.

If MRI can detect most cancers, it will be more useful to have a scan done before biopsy, especially in intermediate-risk patients. Although more expensive, MRI has many advantages over conventional biopsy. First, biopsy-induced artifacts make T2-weighted scans more difficult to interpret and overestimate cancer, a problem that is only partly mitigated by the use of spectroscopy [113]; The chances of biopsy artifact due to hemorrhage or edema can be eliminated if MRI is done prior to biopsy. Second, MRI-targeted biopsies should also increase the cancer detection rate. Although biopsies targeted at abnormal areas on MRI have a high likelihood of being positive [22, 27, 99], convincing data have not yet been produced to show that MRI-directed biopsy increases overall cancer detection rate. This could be due to lack of a study of sufficient power having been conducted. Cancer detection rates can also be increased by emerging techniques of image fusion in which ultrasound data are fused with MR scanning data [114], whether by pure image processing or coregistration using a positioning marker on the ultrasound probe. Another potential approach to this problem is MR-guided prostate biopsy [86], but this is a time-consuming technique and first needs to demonstrate clear advantages over conventional TRUS before its cost and complexity can be justified. Third, a negative MRI result should increase the NPV of a set of negative biopsies and might eliminate the need for rebiopsy. Comet-Battle *et al*. demonstrated in a screening population of 92 patients that a negative unenhanced MR scan had an NPV for cancer on subsequent transrectal biopsy of 91% [23]. A study by Perrotti *et al*. in a group of 35 patients with previous negative biopsies found that a low-probability MR scan had an NPV of 94% for repeat biopsy, with positive scans having a 40% PPV [27]. These results suggest that a negative MR scan is as reassuring for absence of cancer as a negative repeat sextant biopsy, and can eliminate the need for further evaluation. It would be even more reassuring with the addition of contrast and spectroscopy.

Multiparametric MRI

Every MRI technique has some limitations; therefore, the combination of multiple MRI techniques may address the current drawbacks of the individual techniques. Kozlowski *et al*. reported that a combination of DWI and DCE-MRI provided better sensitivity in detecting prostate cancer [115]. Combined DWI and spectroscopy increased the specificity for prostate cancer detection while retaining the sensitivity compared with MRSI alone or DWI-MRI alone [19]. Various protocols for a combined MRSI and DCE have been evaluated in multiple patient cohorts [14, 116, 117]. However, a large prospective study combining various MR techniques (T2, dynamic-enhanced, spectroscopy, and diffusion) and with a long-term follow-up has not yet been performed and must be one of the major goals of research in this field. This may not only validate the superiority of multiparametric MRI over individual techniques, but will also answer a few questions, such as what proportion of cancers can be detected using the multiparametric MRI?; what is the NPV of a scan that is normal using each sequence?; are some cancers invisible regardless of the modality used?; and are these cancers likely to be of significant size or grade?

Conclusions

The future of eMRI in prostate cancer will depend on its ability to detect prostate cancer, especially in the setting of negative biopsy findings; to determine biologic aggressiveness and predict nodal extension; and to distinguish local and distant recurrences after treatment. Conventional MRI is unlikely to yield significantly better results in the future; therefore, functional imaging is our most immediate hope with the development of molecular imaging. This will require the combined skills of scientists and physicians in the fields of molecular biology, pharmaceutical chemistry, radiology, pathology, and urology.

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CHAPTER 119

Angioembolization in Urology

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History

In the 1970s, angiography played an integral role in the diagnosis of renal masses and has been part of the urologic armamentarium for the last 40 years. In 1979, Clayman *et al*. outlined the algorithm which relied on presurgical angiography for the diagnosis and assessment of the asymptomatic renal mass [1] (Figure 119.1). Since then, the indications and applications for angiography and embolization in urology have expanded significantly, although angiography has been supplanted by computed tomography (CT) and magnetic resonance (MR) angiography as well as venography. Angioembolization has been utilized in the treatment of varicoceles, benign prostatic hyperplasia (BPH), pelvic congestion syndrome, preoperative tumor embolization, nonischemic priapism, angiomyolipoma, and postsurgical bleeding from the prostate, kidney and bladder. The goal of this chapter is to provide an introduction to the use of angioembolization in modern urology.

Renal angiography and embolization

The indications for renal angiography and embolization have changed since 1973, when Almgard *et al.* described the first renal embolization to treat renal cell carcinoma [2]. Indications for renal embolization varied from refractory bleeding and recurring infections to nonoperative candidates for definitive therapy. Indications currently include the treatment of angiomyolipoma (AML), preoperative tumor and/or tumor thrombus embolization, control of postoperative renal hemorrhage, pretransplant embolization of native kidneys or failed allographs, patients with end-stage renal disease and uncontrolled hypertension, and arteriovenous malformations/fistulas.

Hom *et al*. investigated the use of complete renal embolization in eight patients unable to tolerate nephrectomy for varying indications (AML, poor function, and/or hemorrhage secondary to malignancy) [3]. The pediatric literature also contains reports of renal embolization as an alternative to simple nephrectomy for severe hypertension or to pretransplant nephrectomy, and for nephritic syndrome and ablation of irreversible rejected renal allograft [4]. In one series, 10 of 12 patients developed severe flank pain, which was the most significant symptom of postinfarction syndrome.

Renal embolization (Figure 119.2) of patients prior to radical nephrectomy remains controversial. Two large series have addressed this issue with differing results. Schwartz *et al*. reported a temporal benefit with regards to blood loss in patients with renal masses greater than 10 cm. The series included 46% (29 of 63) of patients who had a tumor thrombus involving the renal vein or inferior vena cava (IVC). The authors recommended that the optimum delay after renal embolization is 24–48 h and an extended delay may be needed in patients with IVC thrombus [5]. However, data from the other series do not support the same conclusion. Subramanian *et al*. investigated patients undergoing radical nephrectomy and IVC thrombectomy and compared those who underwent preoperative renal embolization with patients who had not. The series included 225 patients

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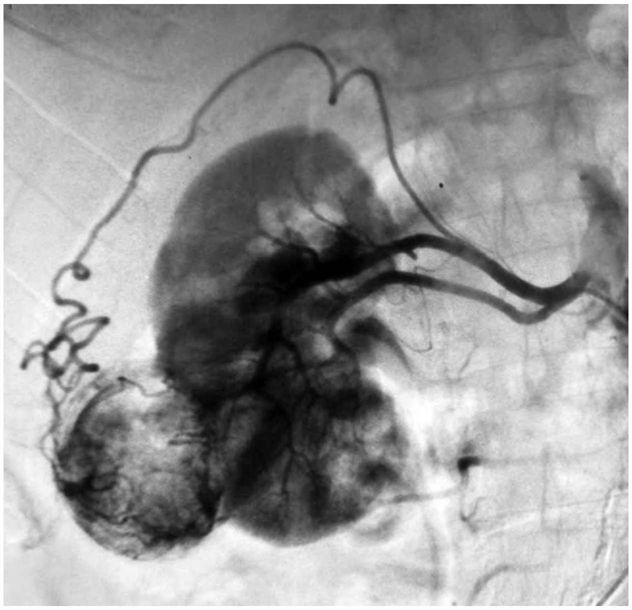

Figure 119.1 Selective angiography delineating a solitary renal mass. Note the enlarged capsular branch partially supplying the tumor, which is typical of renal cell carcinoma.

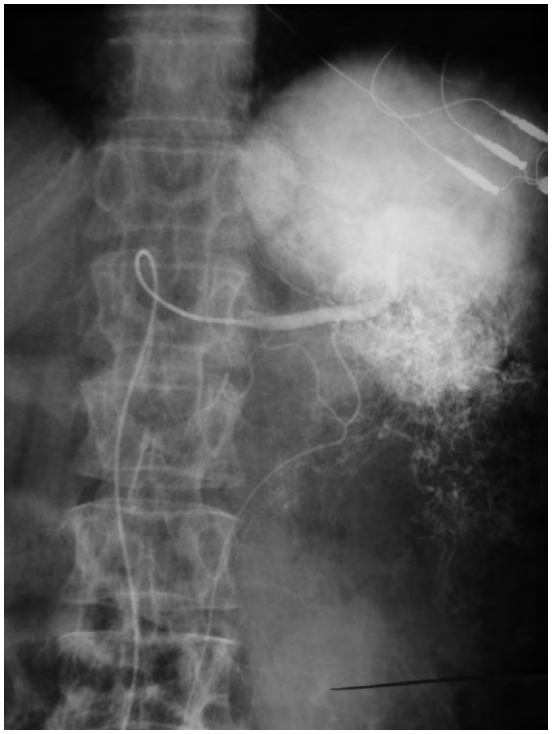

Figure 119.2 Renal angiography of a large renal mass prior to embolization.

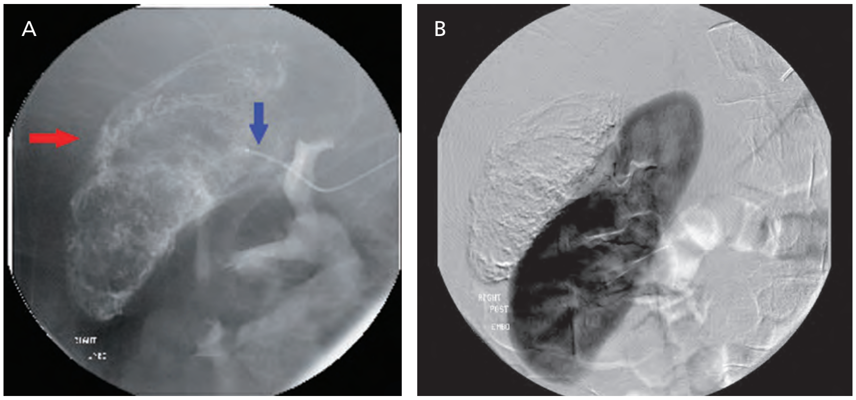

Figure 119.3 (A) Pre-embolization angiogram of an angiomyolipoma (red arrow), with the microcatheter identified by the blue arrow. (B) Postembolization angiogram demonstrating devascularization of the tumor.

and reported no benefit with preoperative embolization in patients with a renal mass and an IVC thrombus [6].

Some of the perceived advantages of preoperative embolization include a reactive edema of tissue planes facilitating dissection and allowing early ligation of the renal vein, a decrease in intraoperative blood loss, and cytoreduction of the tumor thrombus volume. Several studies have examined intraoperative blood loss; however, they are difficult to compare. One study suggests a significant decrease in the volume that is transfused post embolization in patients with large hypervascular tumors [7]. Giuliani *et al*. reported a similar reduction in patients with T3/T4 disease [8]. No specific recommendations can be gleaned from these heterogeneous patient data; therefore, the course of action is still left to the clinician to determine. A dialogue between urologist and interventional radiologist is essential in determining the individual treatment plan that is appropriate for each specific clinical situation.

Selective renal embolization has played a major role in the treatment paradigm of AML (Figure 119.3). In a literature review by Nelson *et al*. of 76 patients with

AML [9], The original 4-cm rule prompting intervention proposed by Oesterling *et al*. [10] held true; however, there were several additional variables that should be taken into account when dealing with these patients: pregnancy plans, patient age, comorbidities, and ability for surveillance [9]. There was a 10% complication rate associated with embolization of AML (not including postinfarction syndrome) and the most common complication was abscess formation (5%); yet, in four of the six larger series, no complications were reported. Fourteen percent of patients required repeat embolization in the meta-analysis [9]; however, this carried little added morbidity for the patient.

Renal artery pseudoaneurysms and arteriovenous fistulas (AVFs) can occur secondary to biopsy, trauma, percutaneous stone extraction, partial nephrectomy, and any other processes that disrupt renal parenchyma. Hematuria can be the presenting symptom if the pseudoaneurysm/AVF is in communication with the collecting system. The incidence in the open partial nephrectomy series from the Cleveland Clinic was 3 of 698 (0.43%) [11] compared to 6 of 345 (1.7%) in the laparoscopic partial nephrectomy (LPN) series from the same institution [12]; obviously, both incidences are very low. Prompt recognition and treatment are crucial to successful management. The diagnosis can be confirmed by CT scan of the abdomen and pelvis with and without contrast. The pseudoaneurysm appears as a focal high attenuation lesion on CT scan [11]. An AVF is characterized by early filling of the venous system on angiography (Figure 119.4). Renal angiography is still the gold standard for diagnosis and therapeutic modality and, based on the degree of suspicion, most patients undergo angiography without prior abdominal imaging (CT scan). Renal surgery is a form of controlled trauma; the use of conservative management as well as embolization in the treatment of renal trauma has been supported by data from the University of California, San Francisco General Hospital [13]. Conservative management or embolization was successful in managing patients with grades I–IV renal trauma, but unfortunately embolization failed in all patients with grade V renal trauma [13].

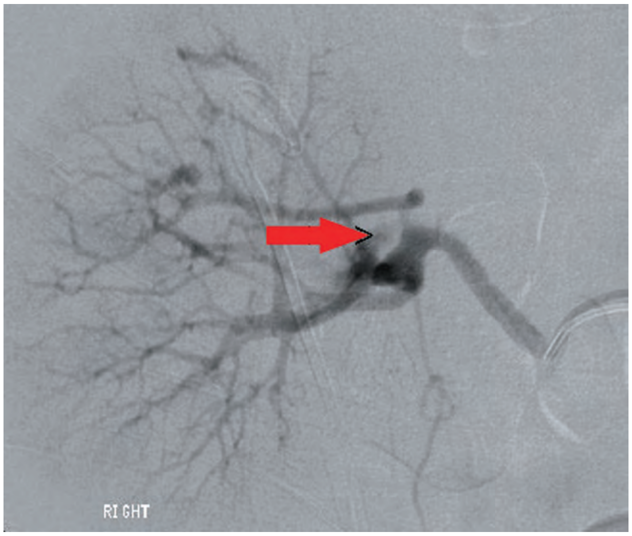

Figure 119.4 Post percutaneous stone extraction arteriovenous fistula (arrow).

Renal embolization is not without complications. The most common complication is postinfarction syndrome, which occurs 24–48 h after the procedure. It can be associated with nausea, vomiting, fever, flank pain, and mild leukocytosis. This occurred in 85% of patients evaluated by Nelson *et al*. [9]. The yield of blood and urine cultures is low in this situation. Management consists of antipyretics and analgesics for the associated pain. In extremely rare cases, tumor fragments have embolized [5].

Technique

Arterial access

The common femoral artery (CFA) is the most common site utilized for renal arterial access. The CFA path runs over the medial aspect of the femoral head (Figure 119.5). This area is important because the femoral head provides the posterior surface on which the physician can apply direct pressure after access has been discontinued, in order to achieve hemostasis. Alternatively, there are several vascular closure systems on the market that can expedite hemostasis, such as the Angioseal device (St Jude Medical, St Paul, MN, USA) and Starclose (Abbott Vascular, Chicago, IL, USA). The Angioseal device uses a vascular plug to maintain hemostasis, unlike Starclose, which utilizes a vascular clip.

First, a hollow-core, single-wall arterial puncture needle, such as a 19G Potts needle (Remington Medical Inc, Alpharetta, GA, USA) or a 21G Micro-puncture needle (Bard Inc, Murray Hill, NJ, USA), is used to access the CFA, typically entering at a 45° angle (Figure 119.6). The needle is then exchanged for a 6F sheath (Cordis Corp, Miami Lakes, FL, USA) over a 0.035-inch J-tipped wire (Cook Inc, Bloomington, IN, USA).

Angiography and catheters

Using the 0.035-inch wire, a 4 or 5F SOS Omni catheter (Angiodynamics, Queensbury, NY, USA) or a Cobra catheter 65 cm (Angiodynamics) is then placed within the origin of the renal artery. A small amount of iohexal contrast (Omnipaque™; GE Healthcare, Waukesha, WI,

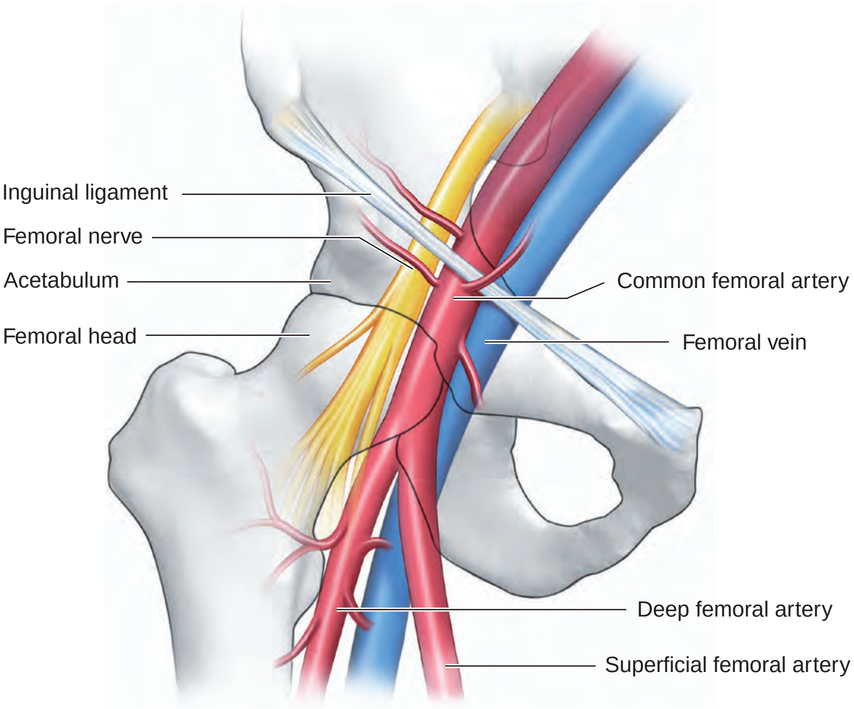

Figure 119.5 Course of the common femoral artery as it travels anterior to the medial aspect of the femoral head prior to its bifurcation into the deep femoral artery and superficial femoral artery.

USA) is injected through the catheter. Digital subtraction angiography (DSA) is performed to minimize the amount of contrast and radiation that the patient receives [14].

Identification of acute bleeding site

Renal arterial anatomy is delineated, and any source(s) of hemorrhage is identified. Common angiographic findings of hemorrhage include AVF, pseudoaneurysms, blind-ending vessels or active extravasations of contrast. AVFs are characterized by early filling of the venous system during arteriography. Pseudoaneurysms are saccular dilations of the arterial branches (Figure 119.7). Finally, lacerated segmental arteries are identified by contrast extravasation from a bluntly ended arterial branch (Figure 119.8).

Once the source of hemorrhage has been identified or still has not been elicited, the diagnostic catheter, or microcatheter, can be advanced and DSA can be repeated as needed. If no obvious source of bleeding is elicited on initial angiography, then we catheterize each of the segmental arteries, specifically arteries near the area of surgery (percutaneous stone extraction tract or partial nephrectomy renorrhaphy sites). An 2.8F microcatheter, 130 cm (Progreat microcatheter; Terumo, Tokyo, Japan) is then utilized through the larger diagnostic catheter, which is anchored in the main renal artery or segmental artery. This allows further investigation more distally into the third- or fourth-order arterial branches towards the origin of the bleeding vessel. A 0.018-inch micro guidewire, such as the Gold Tip glidewire (Terumo) or the Fathom Steerable guidewire (Boston Scientific, Natick, MA, USA) is used to probe and manipulate the catheter into the distal vessels.

Embolization

Using the findings on angiography, the physician needs to take into account the goal of embolization. If a tumor is to be embolized prior to nephrectomy or partial nephrectomy [15], then the entire tumor circulation needs to be occluded, in contrast to a postoperative patient presenting with bleeding from the surgical site. The most common agents for tumor embolization are liquids (99% ethanol), PolyVinyl Alcohol PVA (Contour; Boston Scientific) or Embospheres (BioSphere Medical, Rockland, MA, USA) can be utilized. These agents allow for distal progression and complete obstruction of the tumor's microcirculation. This is in contrast to occluding one specific bleeding vessel, for which glue or coils can be employed [16].

Microcoils such as the AZUR (Terumo) and Interlock (Boston Scientific) are currently the most common embolic devices utilized for renal embolization performed for a distinct arterial bleeding source (Figure 119.9).

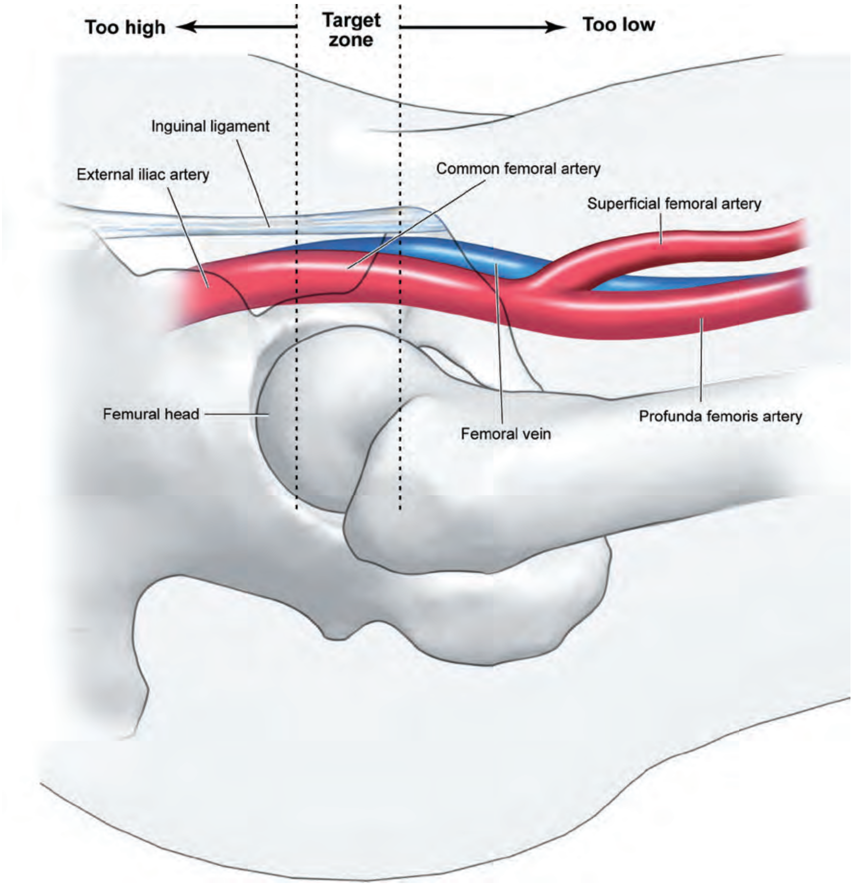
Too high
Target zone
Too low
Inguinal ligament
External iliac artery
Common femoral artery
Superficial femoral artery
Femural head
Femoral vein
Profunda femoris artery

Figure 119.6 Suggested target zone for arterial puncture inferior to the inguinal ligament, above the superficial femoral artery–deep femoral arterial bifurcation and anterior to the femoral head.

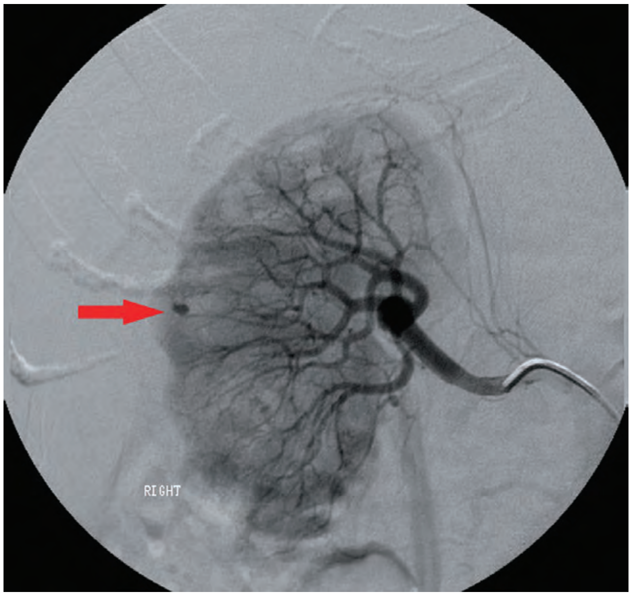

Figure 119.7 Pseudoaneurysm (arrow) observed on renal angiography.

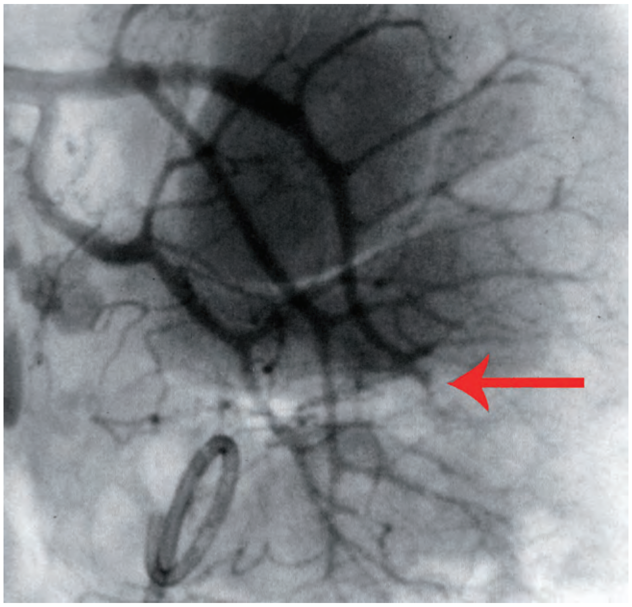

Figure 119.8 Blind ending vessel (arrow) on renal angiography following percutaneous stone extraction.

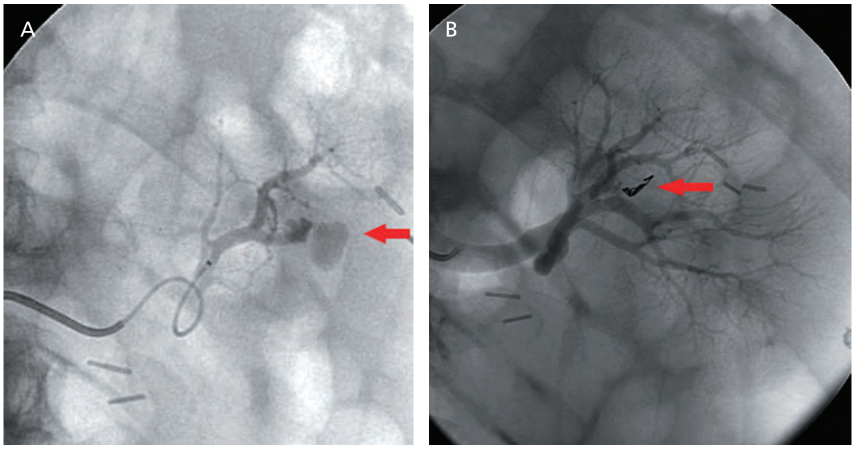

Figure 119.9 Pseudoaneurysm (arrow) (A) post partial nephrectomy and (B) post coil embolization.

Once hemostasis has been obtained by embolization, completion angiography is performed through the microcatheter as well as the diagnostic catheter to document effective embolization and assess the percentage loss of renal parenchyma.

Bladder angiography and embolization

Hemorrhagic cystitis is a common urologic problem with numerous causes. Pelvic radiation, infectious diseases (bacterial/viral), systemic diseases (rheumatoid arthritis, Crohn disease, amyloidosis), chemical cystitis (cyclophosmphamide, other alkylating agents), and medications (penicillin derivatives) have all been implicated as causes of hemorrhagic cystitis [17]. The treatment of the resultant hematuria and possible hemorrhage is directed individually at the primary etiology. Probably the most common cause of hemorrhagic cystitis is associated with a bacterial/viral infection; this is usually underreported because it is easily treated with appropriate medications and is self-limiting.

In patients with more severe hemorrhagic cystitis, several factors need to be addressed. First, it is important to understand the etiology of the hemorrhagic cystitis. For example, radiation cystitis is secondary to obliterative endarteritis of vessels while infectious causes lead to mucosal inflammation and bleeding. The additional treatment options are very different if conservative management strategies fail in these two patient groups.

Several treatments and strategies can be employed for hemorrhagic cystitis. In 1974, Hald and Mygind first reported the use of muscle fragments to emobolize a unilateral hypogastric artery in order to control severe bladder hemorrhage [18]. Since then, there has been significant progress in techniques and equipment. The goal is always to preserve as much functioning organ tissue as possible and to avoid nontarget embolization. Embolization has been employed as an adjunct to the normal treatment paradigm after all other treatments have failed. The indications for embolization have included refractory hematuria secondary to viral infection, cyclophosphamide, bladder/prostate malignancies, amyloidosis, and radiation cystitis [17].

Prostate angiography and embolization

Hematuria is a well-documented symptom of prostatic disease (BPH or cancer) and lead to significant morbidity. The incidences of hematuria associated with BPH, prostate cancer, and external beam radiation of the prostate are 20%, 0.7%, and up to 0.5%, respectively [19]. The majority of patients with hematuria can be easily diagnosed and treated noninvasively. Hematuria is treated initially using a functional approach, directly addressing the hematuria with Foley catheter drainage, clot evacuation, irrigations, and transurethral fulguration/resection of the bleeding tissue. Also, depending on the etiology, a biochemical approach can be used, which could consist of 5-alpha-reductase inhibitors or androgen deprivation.

In the extreme situation of a patient with refractory hematuria, some authors have advocated open surgical and/or endoscopic management. One option for patients with refractory prostatic hematuria is selective arterial prostatic embolization (SAPE) (Figure 119.10) [20]. We treated eight patients with refractory hematuria and 100% had cessation of the life-threatening hematuria; however, this procedure is not without complications. One patient with T4 prostate cancer invading the rectum developed a rectoprostatic urethral fistula after embolization [20]. We believe the risk of fistula is extremely low, except in this unique situation in which

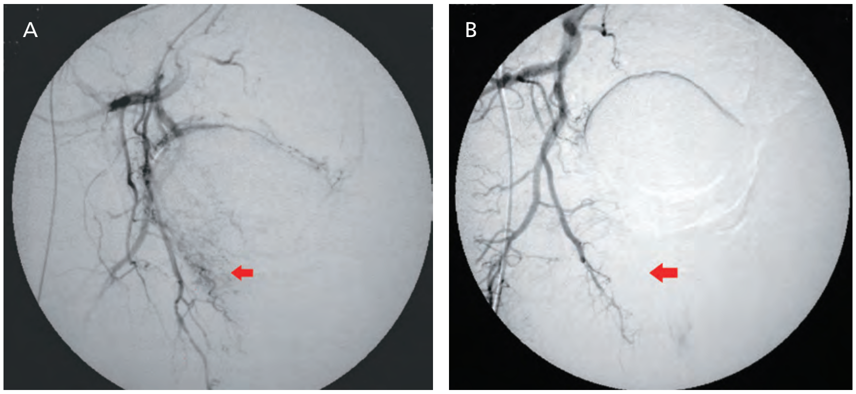

Figure 119.10 (A) Selective angiography of internal iliac artery demonstrating neovascularity (arrow). (B) Follow-up angiography demonstrates pruning of neovascularity of the prostate (arrow).

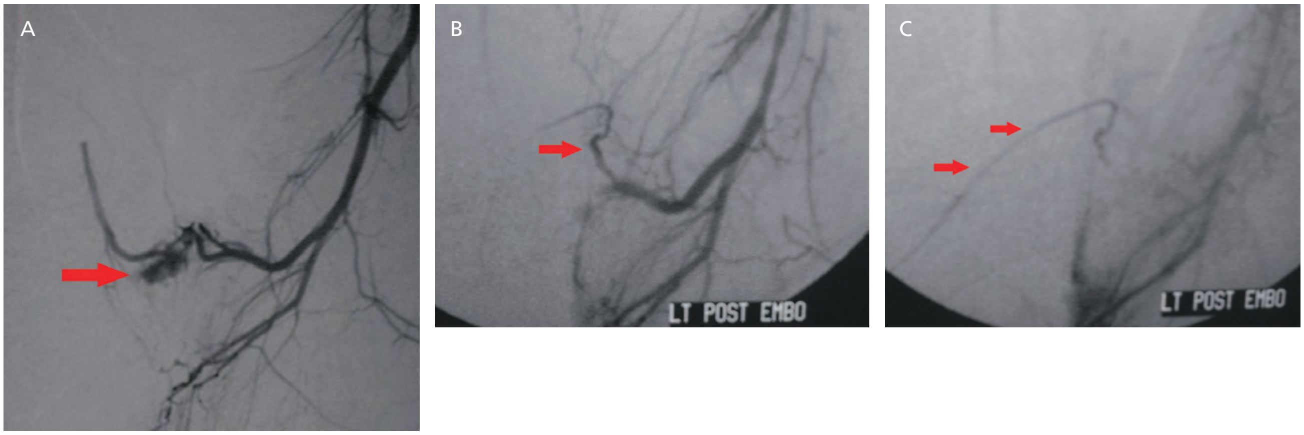

Figure 119.11 (A) Selective angiogram of the internal pudendal artery with an arteriovenous fistula into the corpora (arrow). (B, C) Post embolization using autologous blood clot mixed with Avitene (temporary agent). (C) Note the closure of the fistula and patency of the penile artery (arrow). (C) Note the distal filling of the penile artery (arrows).

the prostate cancer had destroyed the natural planes and rectal wall.

Recently, the indications for SAPE have been expanded by some authors to treat BPH [21–23]. There has also been some preclinical work in a hormone-induced BPH canine model [24]. The approach used differs between the small case series, depending on the embolization agent used and the type of postprocedural follow-up. These researchers' data do appear to be the groundwork for a new emerging treatment in BPH. They further reinforce the need for cooperation between urologist and interventional radiologist to better understand the treatment options for these patients. Selective embolization has also been employed as an alternative to returning to the operating room after radical prostatectomy. Several authors have reported on the use of selective embolization to control bleeding after radical prostatectomy or transurethral resection of the prostate [25–28].

Penile embolization [nonischemic (high-flow) priapism]

Priapism can be divided into two categories, the low-flow or ischemic variety, and the less common high-flow (nonischemic) variety. The latter has typically been treated with observation and embolization. High-flow priapism can be secondary to trauma or occur post treatment of ischemic priapism [29]. The American Urological Association (AUA) guidelines recommend observation for the initial treatment of high-flow priapism: 62% of patients had resolution and 33% patients complained of erectile dysfunction [30].

If observation fails or the patient requests definitive treatment of nonischemic priapism, selective embolization is the treatment of choice. The goal of embolization is to close the AVF, which is the cause of the high-flow priapism (Figure 119.11) [31]. It is important to consider which embolic agent to utilize because data reveal a difference in degree of postoperative erectile dysfunction when comparing permanent versus temporary embolic agents (39% vs 5%, respectively) [30]. The resolution rates are similar after embolization, for permanent and nonpermanent embolic agents (78% vs 74%, respectively). Surgical management is a last-resort option which carries a lower success rate (63%) and a higher rate of erectile dysfunction (50%) [30].

Varicoceles

Varicoceles are present in 15% of male adolescents, with a very strong left-sided predominance [32]. The evaluation of men presenting with subfertility reveals a varicocele as the etiology in one in three patients [33]. Current indications for intervention include infertility in the adult male, pain, and asymmetric testicular growth (>2 mL or 20% volume difference) in the adolescent [34]. Kass *et al*. reported that 80% of the adolescent patient population after varicocele treatment may exhibit catch-up growth [35].

The direct benefit of treating varicocele for subfertility is difficult to assess due to the lack of randomized controlled trials. Using the data available, there is an approximate 15% increase in fertility rates when compared to control groups [36]. Argarwal *et al*. performed a meta-analysis and reported improvement in semen parameters in men treated for a palpable varicocele and abnormal semen analysis [37].

Several different approaches can be employed in the treatment of varicoceles, including mass ligation or a microsurgical approach to embolization (Figure 119.12). The failure rates need to be considered; as low as 1% was reported for the microsurgical approach [38] and 5.9% for embolization (208 of 221) [39]. There is also a significant difference in the incidence of hydrocele with each technique; it is much higher in patients treated using the Palomo technique compared to embolization (8.2% vs 0%, respectively [38]. There is still no clear-cut data regarding the best technique as these are limited and authors have treated heterogeneous populations of men with varying degrees of subfertility.

Pelvic congestion syndrome

Pelvic congestion syndrome is thought to be secondary to venous valve incompetence and dilation of periovarian/periuterine varices (Figure 119.13), which is often exacerbated during pregnancy when ovarian blood flow can be increased to 60 times that of normal [40]. Investigators have evaluated the use of sclerotherapy/embolization to treat these patients, which is analogous in theory to the treatment of varicoceles but requires the use of sclerotherapy. This is due to the complex network of plexi allowing for communication between the bilateral ovarian and internal iliac venous systems. Sclerotherapy is usually performed with 3% sodium tetradecyl sulfate foam (Angiodynamics).

These patients have been treated with a medical approach aimed at decreasing venous pooling by utilizing medroxyprogesterone acetate to induce venous contraction [41]. Venous embolization has shown a complete or partial treatment success in 73.7% (14 of 19 patients) [42]. Several other investigators have confirmed similar findings in the treatment of pelvic congestion syndrome [43, 44].

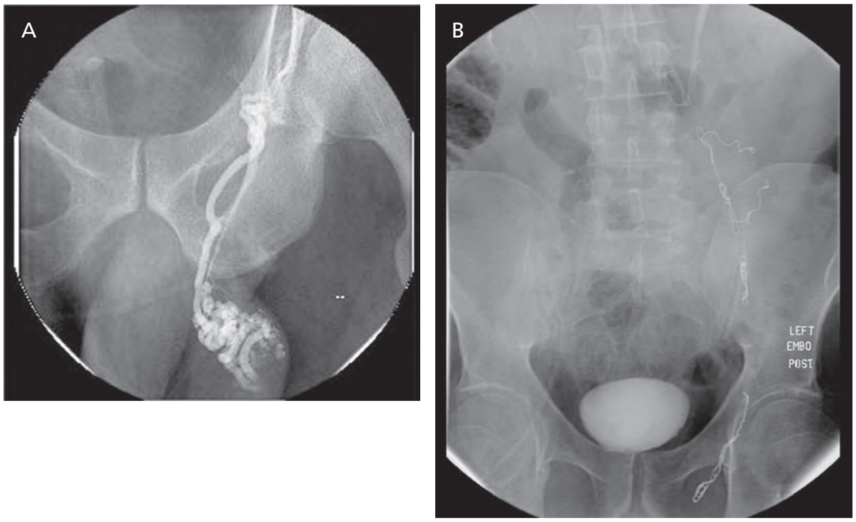

Figure 119.12 (A) Gonadal venography demonstrating a left-side varicocele. (B) Post embolization. The goal is to embolize at multiple levels: inguinal canal, inferior and superior boarder of sacrum, and just prior to the insertion of the gonadal vein into the renal vein (left side) or vena cava (right).

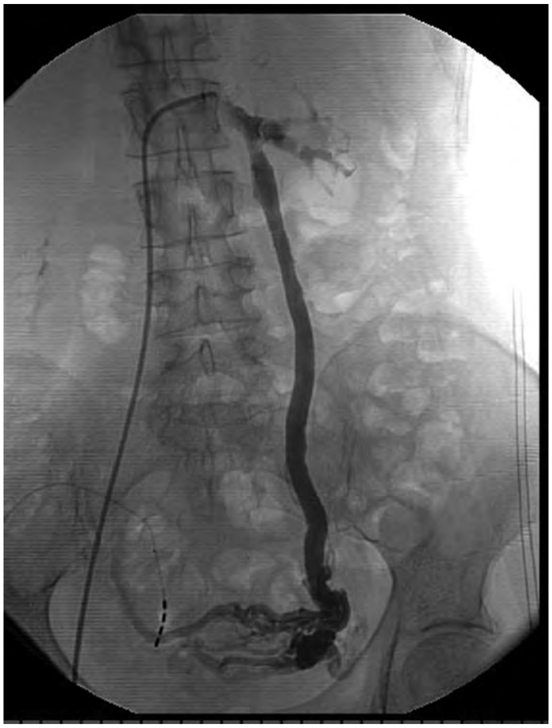

Figure 119.13 Pelvic congestion syndrome with reflux into the periuterine/periovarian venous plexus demonstrated on venography.

Conclusions

Over the past 50 years, urologists and interventionalists have worked together to treat urologic patients. Minimally invasive therapies have led a revolution in the way we take care of our patients. Angiography and embolization have taken their place as well within the urologic armamentarium. As collaborative efforts continue within our disciplines, the role of angiography in urology will continue to expand.

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SECTION 8
Lower Urinary Tract

CHAPTER 120

Assessment of Outflow Obstruction and Sphincteric Incontinence in Men: A Urodynamic and Fluoroscopic Perspective

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Introduction

Benign prostatic hyperplasia (BPH) is an age-dependent pathoanatomic condition with an initial histopathologic development after 40 years of age, and prevalence rates of approximately 50% and 90% by 60 and 85 years of age, respectively. Cell proliferation associated with BPH is comprised of both epithelial and stromal elements and may result in benign prostatic enlargement (BPE), which can cause bladder outlet obstruction (BOO) and a constellation of lower urinary tract symptoms (LUTS) that are commonly classified as "obstructive voiding" or "irritative storage."

In most instances, the patient has more than one complaint. It has generally been assumed that obstructive symptoms are caused by prostatic obstruction and that irritative symptoms are caused by inflammation or detrusor overactivity. Despite the logic implied, most clinical studies that document the relationship between symptoms and underlying pathophysiology have established no such correlation.

Although existing medical and surgical interventions attempt to reduce the obstructive component to provide symptomatic relief, the association between BPH, benign prostatic obstruction (BPO) and BOO is complex. For example, it is unclear whether urethral obstruction is the primary mechanism by which BPH causes symptoms. Nor is it known whether the relief of the obstruction is a prerequisite to successful treatment of symptoms. Likewise, the relationship between symptoms and commonly used indices of prostatism, such as uroflow and postvoid residual urine, is unknown.

Recent evidence suggests that the etiology of prostatic symptoms is multifactorial involving (1) prostatic urethral obstruction, (2) impaired detrusor contractility, (3) detrusor overactivity, and (4) urgency [1]. The best method to definitively diagnose BOO is the detrusor pressure–uroflow flow study (PFS), but there is much more to be obtained from urodynamics than simply diagnosing obstruction.

This chapter will describe existing urodynamic techniques used in the diagnosis of BPH, as well as review the role of urodynamics in the evaluation of LUTS and urinary incontinence.

Background

LUTS are generally categorized into storage and emptying symptoms. Storage symptoms include urinary frequency, urgency, urge incontinence, nocturia, and bladder/urethral pain during filling. Emptying symptoms comprise of hesitancy, straining to void, weak force of stream, a feeling of incomplete bladder emptying, and urinary retention. In men, BOO resulting from BPH is only one of many causes of LUTS. Others causes include idiopathic and neurogenic detrusor overactivity, urgency impaired detrusor contractility, and polyuria. It is not possible to make the diagnosis of BOO on symptom

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assessment alone. In patients with LUTS, urodynamic evidence of BOO exists in only 50–66% of patients [2–5]. A number of studies have demonstrated a lack of correlation between symptoms, American Urological Association (AUA) symptom score or the Danish Prostate Symptom Score and any urodynamic data in patients with suspected BPH and BOO [6–9].

Determining the urodynamic abnormalities responsible for LUTS is important so that treatment can be directed at the underlying pathophysiology. Currently, the majority of medical and surgical interventions target the reduction or elimination of prostatic obstruction, yet only about two-thirds of men are actually obstructed. In fact, therapies should be specific for detrusor overactivity, urgency, and impaired detrusor contractility, and urodynamics are necessary to make the distinctions between these entities. The most definitive method of diagnosing obstruction and impaired detrusor contractility is the detrusor pressure–uroflow study, whereas only cystometry is necessary to distinguish urgency and detrusor overactivity. Although uroflow, postvoid residual urine volumes (PVR), symptom analysis, and questionnaires all play a role in evaluating men with suspected BOO, only urodynamics can make the necessary distinctions to allow therapy to be tailored to the underlying condition.

Table 120.1 Relevant data before and after treatment.

- Structured micturition history
- Global assessment score, such as the AUA or the Overactive Bladder Symptoms Score
- Physical examination including:
  - General examination
  - Brief screening neurologic examination (to discriminate normal, paraplegic, quadriplegic, hemiplegic, dementia, etc.)
  - Focused neurologic examination (perianal sensation, anal sphincter tone and control, and bulbocavernosus reflex)
  - Prostate examination
- A micturition diary including:
  - Time of micturition
  - Description of symptoms
  - Voided volume
- Uroflow (Q) and postvoid residual determination (PVR):
  - Urodynamic parameters: the following parameters permit patients to be objectively classified as having prostatic obstruction or impaired contractility:
    - i. Maximum uroflow (Qmax)
    - ii. Detrusor pressure at maximum flow (pdet@Qmax)
  - Other useful urodynamic parameters include:
    - i. Presence or absence of detrusor overactivity
    - ii. Bladder sensation and ability to abort involuntary detrusor contractions
    - iii. Bladder capacity
    - iv. Voided volume

Defining and quantifying symptoms

To evaluate the outcomes in any meaningful way, it is necessary to tabulate relevant data before and after treatment (Table 120.1).

Preparation for a urodynamic study

The main purpose of urodynamic evaluation is to document the underlying cause of the patient's complaints and to correlate symptoms with urodynamic findings. From a clinical standpoint, the purpose of urodynamic testing is to measure and record various physiologic variables while the patient is experiencing those symptoms that constitute his usual complaints. Thus, in this context urodynamics should be considered to be a provocative test of vesicourethral function, and it is the responsibility of the examiner to insure that the patient's symptoms are reproduced during the study. To this end, it is important that the examiner has all relevant clinical information prior to and during the urodynamic study. For example, the examiner should have results of fairly extensive evaluation including (1) a focused history and physical examination, (2) urinalysis ± culture, (3) a 24-h bladder diary, (4) a 24-h pad test (for patients with incontinence), (5) uroflow, and (6) PVR.

Further, in order to interpret urodynamic studies more accurately, the following information should be available to the examiner before the start of the study:

a. What symptoms are you trying to reproduce?
2. What is the functional bladder capacity (maximum voided volume on the voiding diary)?
a. What is the PVR?
3. What is the uroflow? (is there likelihood of either urethral obstruction or impaired detrusor contractility?)
a. Is there a neurologic disorder that could cause neurogenic bladder?

The multitude of urodynamic techniques and parameters may confound the practicing physician, but in principle there are only five: cystometry, uroflow, leak point pressure, sphincter electromyography, and radiographic visualization of the lower urinary tract. Each technique may be performed alone or synchronously with one another. When done synchronously, the tests are called multichannel urodynamics and when performed with fluoroscopic visualization of the lower urinary tract, videourodynamics. In the following section, use of each urodynamic technique in the evaluation of lower urinary tract symptoms will be explained.

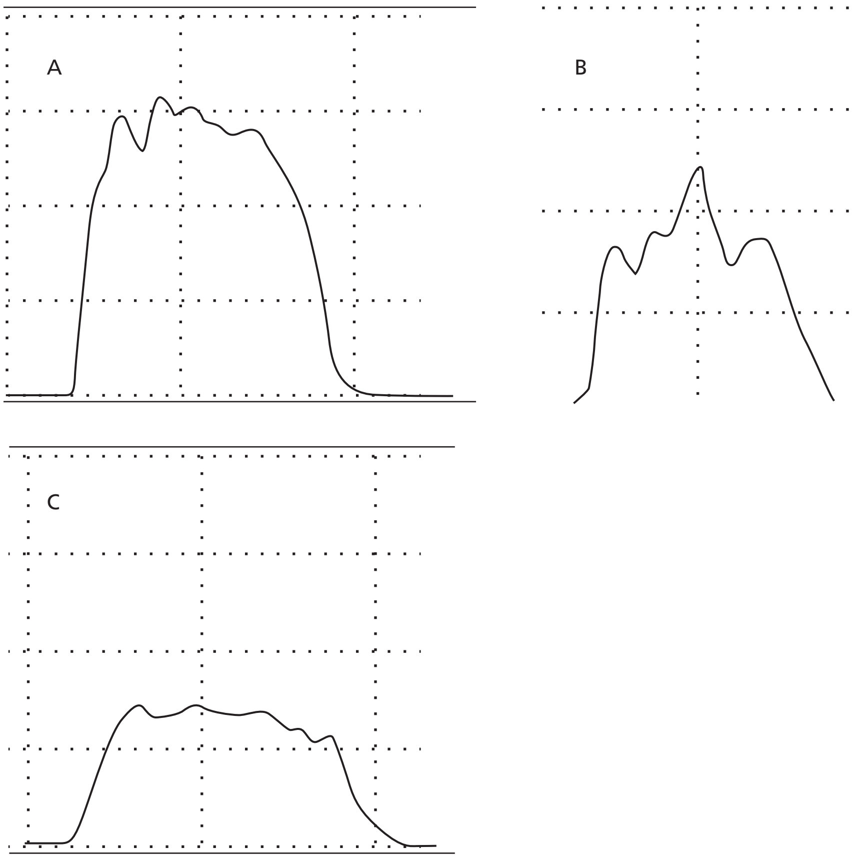

Figure 120.1 (A–D) Normal continuous uroflows. (A) Normal uroflow in a 52-year-old man. The pattern is continuous and the curve is very slightly fluctuating. Maximum flow (Qmax) = 31 mL/s; average flow rate (Qave) = 22 mL/s; voided volume = 269 mL; postvoid residual volume (PVR) = 0 mL. (B) Normal uroflow in a 53-year-old man. The pattern is continuous and the curve is fluctuating. Qmax = 24 mL/s; Qave = 13 mL/s; voided volume =190 mL; PVR = 0 mL. (C) Normal uroflow in a 59-year-old man. The pattern is continuous and the curve is slightly fluctuating. Qmax = 15 mL/s; Qave = 10 mL/s; voided volume = 200 mL; PVR = 10 mL.

Evaluation of lower urinary tract symptoms

Voiding symptoms with uroflowmetry

In general, voiding symptoms have one or more of three basic underlying etiologies: BOO, impaired detrusor contractility, and/or detrusor overactivity. BOO is characterized by a detrusor contraction of adequate magnitude (pressure) and duration, and a diminished flow. Impaired contractility is characterized by a weak or poorly sustained detrusor contraction and a low flow.

Uroflowmetry is a simple, objective, and noninvasive method to evaluate LUTS. Uroflowmetry is not used to evaluate filling symptoms. It should be performed in a private setting with the patient sitting or standing to reproduce normal voiding patterns. From simple uroflowmetry maximum urinary flow (Qmax), flow pattern, voided volume, and shape of curve can be obtained. After voiding, the PVR is recorded with ultrasound or catheterization if invasive urodynamics are to follow.

Uroflowmetry is best performed when the patient experiences a normal desire to void. A minimum urine volume of 150 mL provides an accurate study [10]. Existing nomograms provide values with age- and volume-adjusted flow rate [6, 7, 11]. A Qmax of greater than 15 mL/s is considered normal, and approximately 95% of patients with this parameter will not be obstructed [12]. A Qmax of less than 10 mL/s is considered abnormal, and of 10–15 mL/s is equivocal [12]. A variety of normal uroflowmetry with normal curves and parameters is shown in Figure 120.1.

Uroflowmetry is unable to distinguish obstructed from unobstructed patients [13]. An equivocal uroflow may be seen in patients with significant obstruction and an abnormal flow may be seen in a patient with poor detrusor function. It is obvious that BOO is associated with a low urinary flow rate, but it may also be associated with impaired contractility. In patients who are obstructed, uroflowmetry cannot differentiate types of urethral obstruction (BPH, urethral stricture, etc.). Figure 120.2 displays two similar abnormal

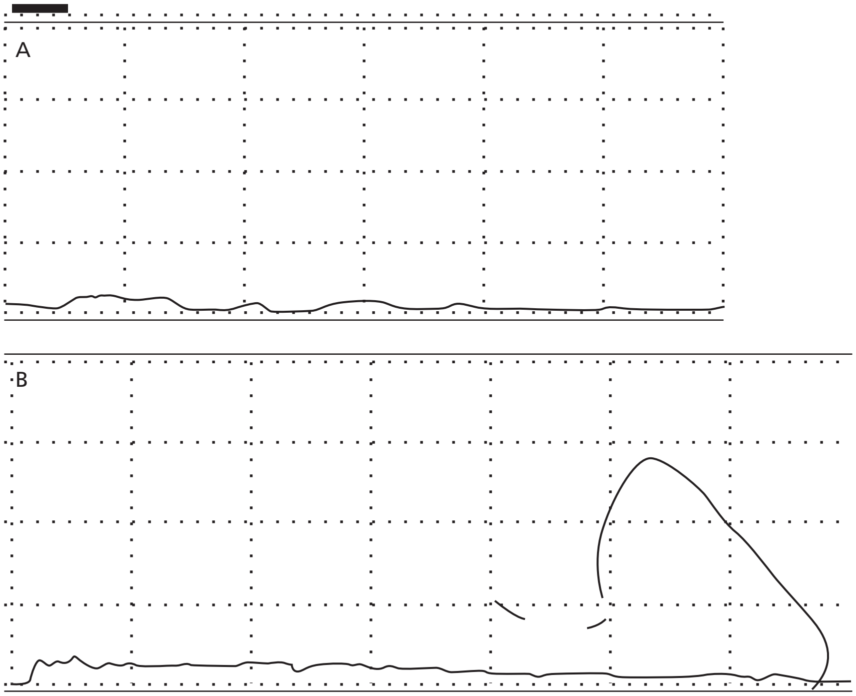

Figure 120.2 (A) Low flow due to impaired detrusor contractility. Maximum flow (Qmax) = 2 mL/s; average flow (Qave) = 2 mL/s; voided volume = 58 mL; postvoid residual volume (PVR) = 120 mL. (B) Low flow due to urethral obstruction. Qmax = 3 mL/s; Qave = 2 mL/s; voided volume = 149 mL; PVR = 212 mL.

uroflowmetry patterns despite their having different etiologies.

Despite these limitations, uroflowmetry remains a useful initial evaluation of men with LUTS. The AUA guidelines (2003) recommend uroflowmetry as an optional test in men with moderate/severe symptoms [14]. However, the European Association of Urology Guidelines on BPH recommend uroflowmetry in the assessment and diagnostic work-up of men with LUTS and is considered mandatory prior to surgical intervention [15].We recommend uroflow for all men with LUTS.

Uroflowmetry remains an important tool in evaluating efficacy of medical and surgical treatments. It is a constant and powerful parameter utilized in reporting outcomes.

Filling symptoms with cystometry

Filling symptoms may be caused by detrusor overactivity, urgency, low bladder compliance, reduced bladder capacity, or polyuria. It is imperative to exclude other underlying causes of filling symptoms, such as urinary tract infection, bladder and prostate cancer, urolithiasis, and neurogenic bladders, prior to urodynamic testing. Polyuria can be caused by excessive fluid intake, diabetes mellitus, diabetes insipidus, and other less common conditions. Nocturia may be the result of abnormal drinking patterns, a reversal of the normal diurnal antidiuretic hormone cycle, congestive heart failure, venous insufficiency, sleep apnea, lower extremity edema, diabetes mellitus, or hypertension.

Filling cystometry is the only method that can document detrusor overactivity, and low bladder compliance; however, it is not useful as a standalone procedure in men with LUTS. Currently, the AUA guidelines recommend that cystometry be done as part of the PFS. In men experiencing LUTS, up to two-thirds may be found to have detrusor overactivity. Despite poor physiologic explanation, resolution of detrusor overactivity can be expected in 50–70% of patients after outlet reduction [16, 17] Figure 120.3 demonstrates an idealized cystometrogram as well as an actual cystometrogram from a patient: note that without abdominal pressure tracings, the cause of vesical pressure increase cannot be determined accurately.

Multichannel urodynamics and videourodynamics

The simultaneous measurement and display of multiple urodynamic parameters is the most precise diagnostic tool for evaluating abnormalities of micturition. As described earlier, the addition of radiographic visualization of the lower urinary tract with multichannel urodynamics is termed videourodynamics. In these studies, radiographic contrast is used as the infusant

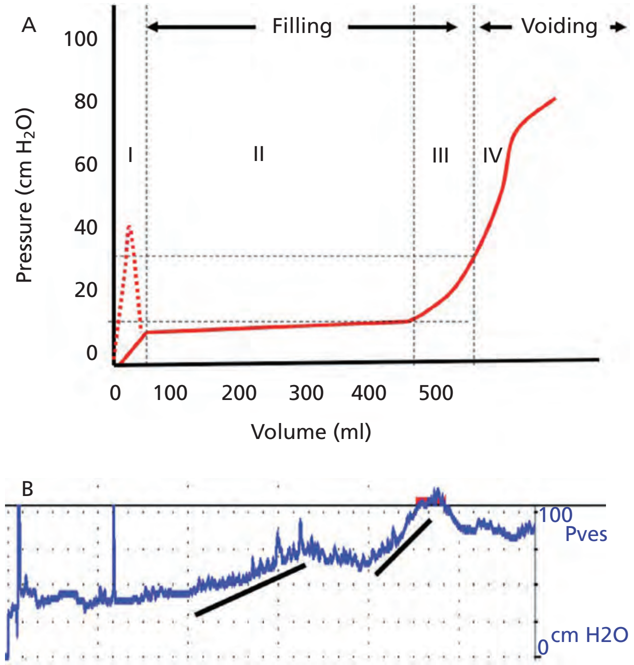

Figure 120.3 (A) An idealized cystometrogram. The dashed red line in phase I is seen only with very rapid filling, such as that attained when CO_2 is used. It is attributed to the viscoelastic properties of the bladder wall. Note that bladder compliance changes at different bladder volumes. Bladder compliance during the tonus limb (phase II) = $400\,mL/10\,cmH_2O = 40\,mL/cmH_2O$; at the end of phase III (500 mL) = $100\,mL/20\,cmH_2O = 5\,mL/cmH_2O$. (B) This cystometrogram demonstrates two steep rises in vesical pressure (pves). The black lines parallel the pressure rises. Without further information, it is not possible to determine whether these are due to straining, detrusor contractions or low bladder compliance.

for cystometry and other urodynamic parameters, including abdominal pressure, uroflow and sphincter electromyography, are recorded as well. By measuring multiple urodynamic variables, a better insight into the underlying pathophysiology is gained, as well a better appreciation of their interrelationships and of artifacts. The International Continence Society has recommended standards for the performance of these studies [18, 19].

The main purpose of urodynamic evaluation is to recreate the patient's complaints and to correlate symptoms to the urodynamic findings. Thus, it is essential to understand the nature of a patient's complaints and to use the urodynamic evaluation as a provocative test to mimic those symptoms, as alluded to above. During the interactive process, the examiner should document whether or not the patient's symptoms are reproduced and, if they are, the underlying cause should be clearly understood before completion of the study.

Urodynamic technique

A uroflow should be obtained prior to the urodynamic evaluation. Then, a 7F double-lumen bladder and rectal catheter are passed into the bladder and rectum to measure vesical and abdominal pressure, respectively, and PVR is measured via the urethral catheter. Pressure transducers are zeroed to atmospheric pressure at the level of the symphysis pubis. The patient should be asked to cough or Valsalva to insure proper reading of instruments on the computer display. Vesical pressure (pves) and abdominal pressure (pabd) are measured directly from the urethral and rectal catheters, respectively, and displayed on a computer screen. Detrusor pressure (pdet) is electronically calculated by subtracting pabd from pves and displayed on a third channel. Other channels display sphincter electromyelogram (EMG), infused bladder volume, filling rate, voided volume, and uroflow. For videourodynamics, fluoroscopic images are sampled periodically as well as at times of events such as urgency and micturition.

Evaluation of filling symptoms

During bladder filling, the presence or absence of detrusor overactivity is noted and bladder compliance recorded. If detrusor overactivity is documented, the patient's awareness, concern, and ability to contract the sphincter, abort the stream, and prevent incontinence are noted. These characteristics are used to classify the type of overactive bladder [20] (Figure 120.4).

Detrusor overactivity is seen in over 50% of patients with BPH, but its presence does not correlate with urethral obstruction [1, 21–23]. A patient with clinical BPH may have detrusor overactivity in the presence of prostatic obstruction. Even in the absence of prostatic obstruction, detrusor overactivity may cause obstructive symptoms. For example, a patient may develop involuntary bladder contraction at a relatively low bladder volume, which is perceived as an urge to void. The patient rushes to the bathroom, however, by this time the involuntary contraction has subsided and there is no longer an urge to void. Attempts to void by the patient with straining and pushing will be unsuccessful due to the small bladder volume. Thus, once it has been determined that there are overactive detrusor contractions, it is important to determine the degree of the patient's awareness, concern, and control.

Evaluation of voiding symptoms

BOO and urethral resistance are defined by PFS parameters. The BOO index (BOOI) is used to measure the degree of obstruction. It is calculated using the formula:

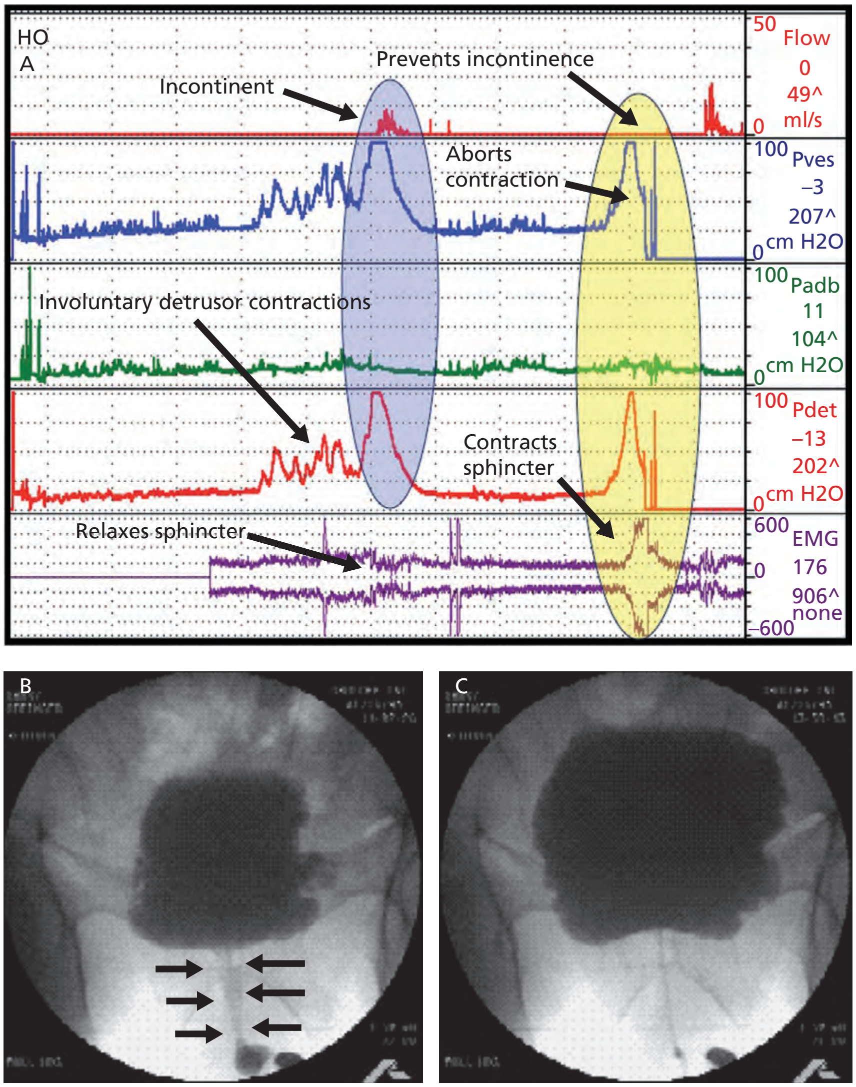
HO
A
Incontinent
Prevents incontinence
Aborts contraction
Involuntary detrusor contractions
Contracts sphincter
Relaxes sphincter
50
0
Flow
0
49^
ml/s
100
0
Pves
–3
207^
cm H2O
100
0
Padb
11
104^
cm H2O
100
0
Pdet
–13
202^
cm H2O
600
0
–600
EMG
176
906^
none
B
C

Figure 120.4 (A) Urodynamic tracing of a Type 2 overactive bladder and prostatic obstruction in a 53-year-old man with a 20-year history of refractory urgency, urge incontinence, and enuresis. During bladder filling the patient is instructed to neither void nor prevent micturition and to report his sensations to the examiner. There are a series of poorly sustained involuntary detrusor contractions (arrow) that he perceives as a severe urge to void, and then there is a sustained voiding contraction whence he relaxes his sphincter and voids (blue oval). Detrusor pressure at maximum flow (pdet@Qmax) = 100 cmH_2O; maximum flow (Qmax) = 8 mL/s (Schafer grade 5 obstruction). The bladder is filled again and there is another involuntary detrusor contraction. This time the patient is instructed to try to hold. He contracts his sphincter, obstructing the urethra, and the detrusor contraction subsides and he is not incontinent (yellow oval). (B) X-ray obtained at Qmax shows a narrowed and faintly visualized prostatic urethra (arrows) characteristic of prostatic obstruction. The bladder is trabeculated and there are several small and medium-sized bladder diverticula. (C) X-ray obtained as the patient contracts his sphincter to prevent incontinence (gray oval). The contrast would be expected to stop at the distal prostatic urethra, but since the patient has prostatic obstruction that narrows the proximal urethra, no contrast is seen in the urethra at all.

$$\mathrm{BOOI} = \mathrm{Pdet\,Qmax} - 2\mathrm{Qmax}$$

where Pdet Qmax is the detrusor pressure at maximum flow. Men are classified as obstructed (BOOI > 40), equivocally obstructed (BOOI > 20 – <40), or unobstructed (BOOI < 20).

Multiple nomograms have been described to interpret PFS [12, 24, 25]. These plot detrusor pressure (at maximum flow) versus the maximum flow rate, and then divide results into unobstructed, obstructed, and equivocal categories. We prefer the Schaefer nomogram because it provides a simple six-point obstruction scale [18]: grade 0–1 is not obstructed; grade 2–3 is equivocal, and grade 4–6 is obstructed.

The urodynamic tracings, fluoroscopic images, and their application to a Schafer nomogram in Figure

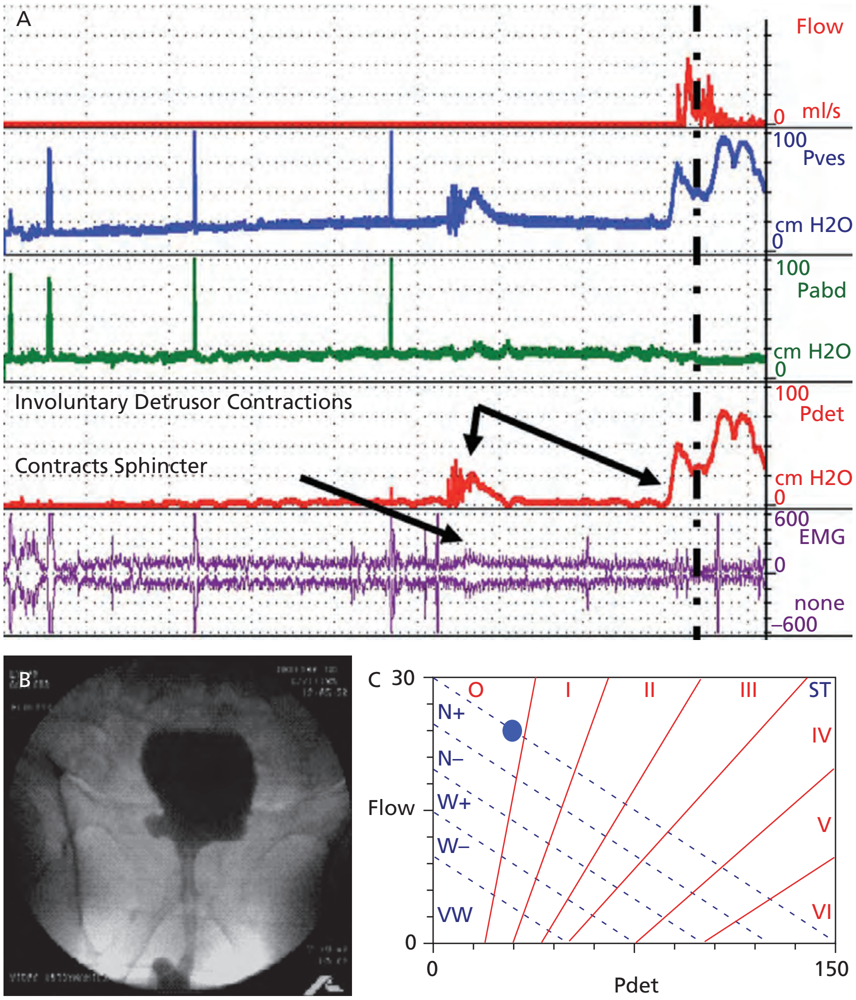

Figure 120.5 (A) Urodynamic tracing of a man with two involuntary detrusor contractions; the terminal one causes incontinence. However, there is no bladder outlet obstruction. Maximum flow (Qmax) = 17 mL/s; detrusor pressure at maximum flow (Pdet@Qmax) = 22 cmH_2O. (B) Voiding cystourethrogram showing a wide open urethra during maximum flow. (C) Schafer nomogram plotting Qmax versus pdet@Qmax, yielding grade 0 voiding with excellent (N+) detrusor contractility.

120.5–120.7 demonstrate the role of each element in the differentiation of LUTS symptoms.

The Schafer nomogram also incorporates bladder contractility in addition to an obstructive index. The slope of Schafer's contractility lines are obtained by the formula for bladder contractility index (BCI):

$$\text{BCI} = \text{Pdet Qmax} + 5\text{Qmax}$$

A BCI greater than 150 is considered to be a strong contraction, a BCI less than 100 is considered to be weak, and a BCI of 100–150 is considered to be normal [26, 27].

Cystoscopy

Urethrocystoscopy is recommended in evaluating men with suspected BPH with a history of microscopic or gross hematuria, prior lower urinary tract surgery, bladder cancer, and urethral stricture. It is not required in those patients who opt for medical therapy. AUA guidelines recommend use of urethrocystoscopy in those patients where the "endoscopic appearance of the prostate may guide the choice of therapy in patients who have already decided to proceed with an invasive approach" [14].

Urinary incontinence

Urinary incontinence occurs in about 5–10% of men with clinical BPH. Most patients have urge incontinence. Sphincteric incontinence in men with BPH does not occur unless the patient has a neurologic condition or has undergone prior surgery or radiation. By far the most common cause of sphincteric incontinence is radical prostatectomy for prostate cancer followed by transurethral prostatectomy, particularly after radiotherapy for

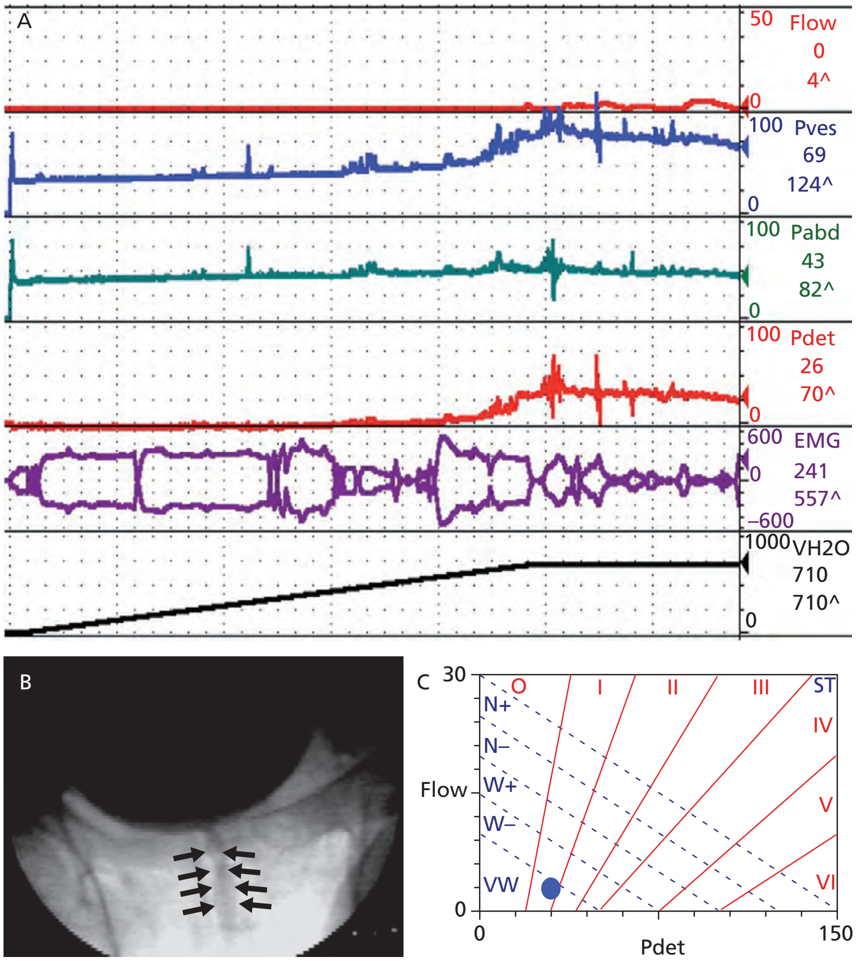

Figure 120.6 (A) Urodynamic study of impaired detrusor contractility (VW) in a 58-year-old man complaining of urinary frequency, urgency, occasional urge incontinence, hesitancy, and weak stream. First sensation of filling (FSF) = 272 mL; first desire = 491 mL; severe desire = 620 mL; bladder capacity = 710 mL; maximum flow (Qmax) = 6 mL/s; detrusor pressure at maximum flow (pdet@Qmax) = 28 cmH$_2$O; maximum detrusor pressure (pdetmax) = 41 cmH$_2$O; bladder contractility index = 58. (B) X-ray obtained at Qmax shows a narrowed prostatic urethra (arrows). (C) Nomogram reveals unobstructed voiding (grade 1) with very weak detrusor contractility. Bladder contractility index = 58.

prostate cancer [28]. Less common causes are neurologic, including thoracolumbar neurologic lesions, such as spina bifida, multisystem atrophy (Shy–Drager syndrome), and after abdominoperineal resection of the rectum.

In the vast majority of patients after radical prostatectomy, incontinence is transitory, usually spontaneously subsiding in a matter of months, although it may take as long as 1 year for full recovery. Sphincteric incontinence that occurs in men who have undergone radiation (external beam or brachytherapy), on the other hand, often does not spontaneously remit. Rather, if incontinence improves, it is usually because of the development of a urethral stricture that begins a vicious cycle. Treatment of the stricture usually results in recurrent incontinence and treatment of the incontinence (sphincter prosthesis or male sling) is often complicated by the development of recurrent stricture [29, 30].

From a diagnostic standpoint, most patients who complain of a constant, dribbling, gravitational or stress-induced incontinence have sphincteric malfunction, and most who complain of urinary frequency, urgency, and urge incontinence have an overactive bladder/detrusor overactivity. However, there may be considerable overlap between these two conditions and both may coexist in the same patient. Sphincter malfunction is the commonest cause of postprostatectomy incontinence (PPI), accounting for about 95% of cases, but it may be accompanied by detrusor overactivity and/or low bladder compliance. As an isolated cause, detrusor overactivity causes about 5% of PPI [31–33].

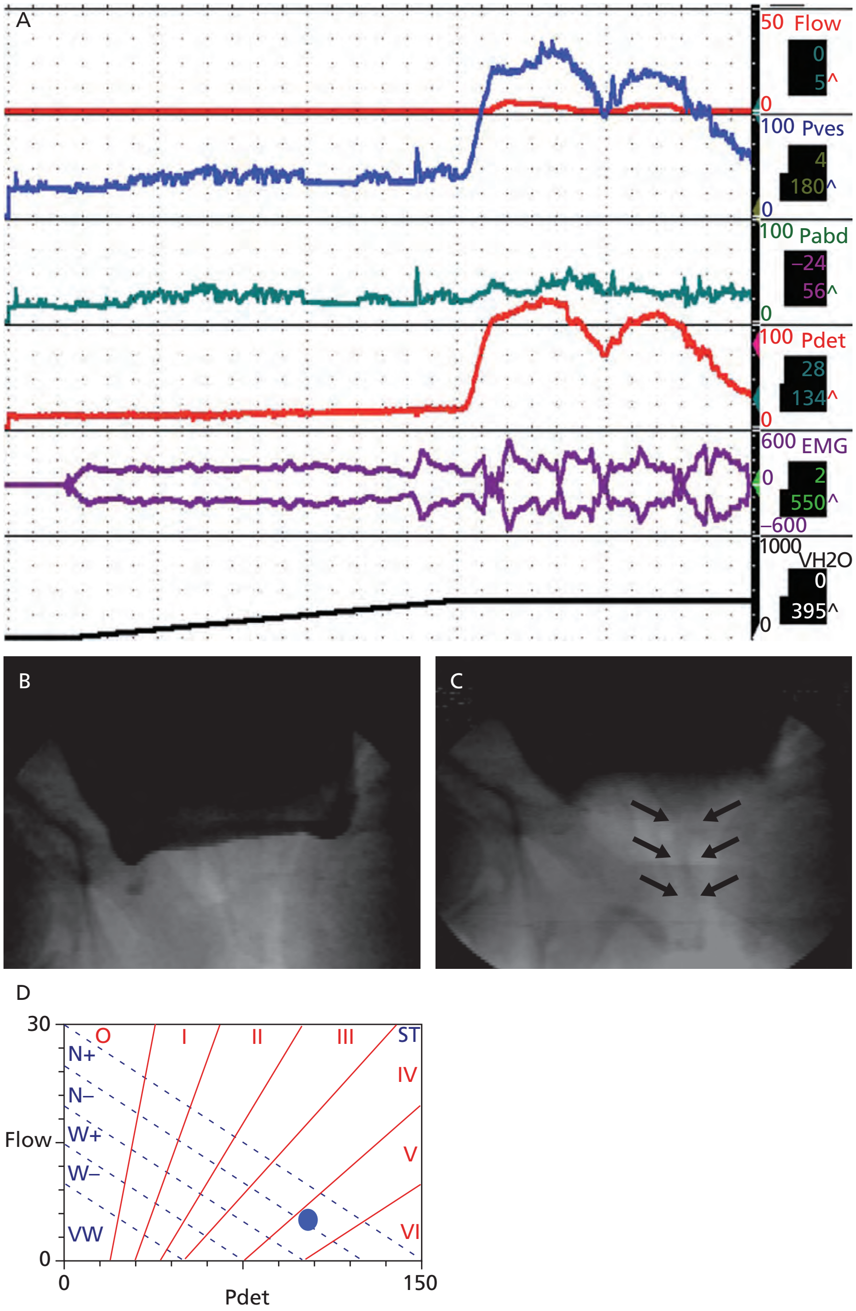

Figure 120.7 (A) Urodynamic tracing of a 63-year-old man with one episode of acute urinary retention on tamsulosin for 5 days. At a bladder volume of approximately 400 mL, the patient had a voluntary detrusor contraction. Maximum flow (Qmax) = 5 mL/s; detrusor pressure at maximum flow (Pdet@Qmax) = 117 cmH$_2$O (vertical line); maximum detrusor pressure (Pdetmax) = 123 cmH$_2$O; voided volume = 215 mL; postvoid residual volume (PVR) = 174 mL. (B) X-ray obtained just prior to voiding shows a flattened bladder base characteristic of benign prostatic obstruction. (C) X-ray obtained at Qmax (vertical line in A) reveals the prostatic urethra to be elongated and barely visible. (D) Detrusor pressure and uroflow plotted on the Schafer nomogram (grade 5 obstruction).

On fluoroscopy, the classic appearance of postradical prostatectomy stress incontinence is the funnel of bladder-urethral anastomosis at rest, with contrast seen in the bulbar or distal urethra during increases in abdominal pressure (Figure 120.8). The presence of and size of the urodynamic catheter used to measure leak point pressure may itself impact the recording and may mask sphincteric incontinence or suggest urethral obstruction when it is not clinically relevant.

In the majority of patients, the etiology of incontinence will be apparent after a careful history, physical examination, voiding diary, and pad test. However,

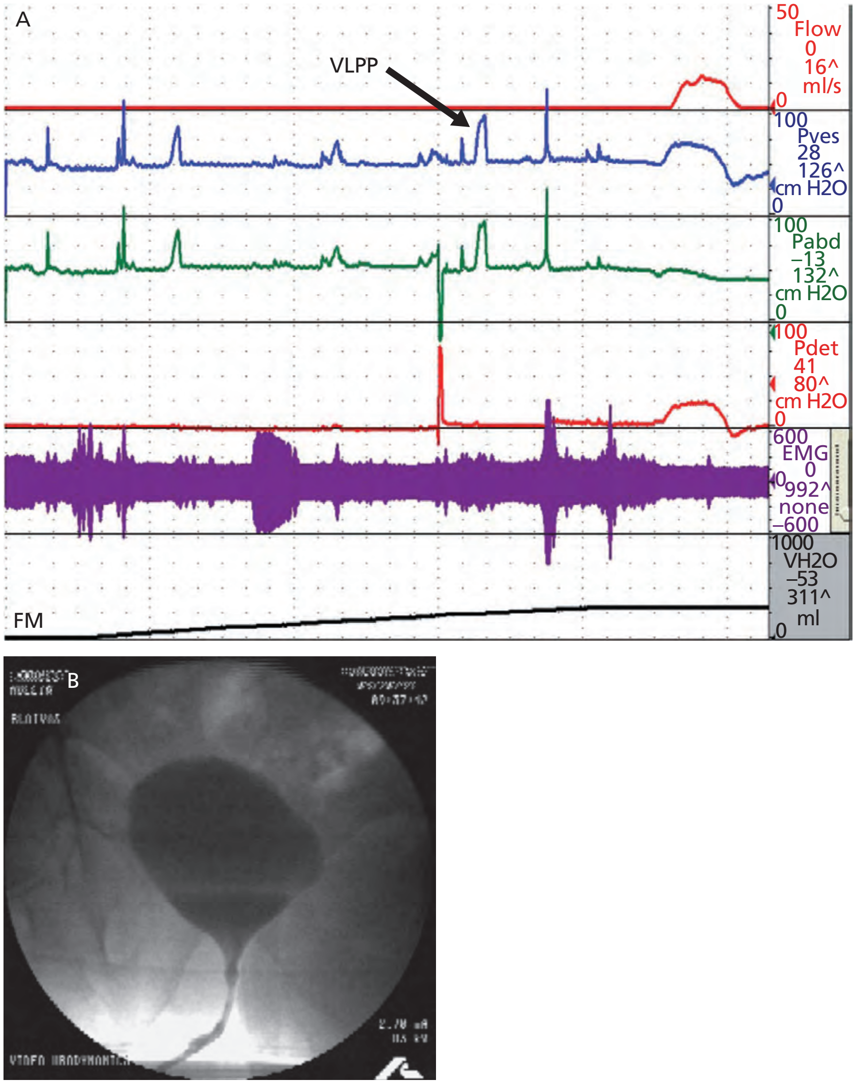

Figure 120.8 (A) Urodynamic tracing of a 72-year-old man 7 years post radical prostatectomy. His only prior treatment for incontinence was a collagen injection. He wears absorbent pads daily and he changes them three times per day. First sensation of filling (FSF) = 211 mL; first urge = 299 mL; severe urge = 305 mL; bladder capacity = 311 mL; Valsalva leak point pressure (VLPP) = 84 cmH$_2$O; maximum flow (Qmax) = 16 mL/s; detrusor pressure at maximum flow (pdet@Qmax) = 23 cmH$_2$O; maximum detrusor pressure (Pdetmax) = 23 cmH$_2$O; voided volume = 317 mL; postvoid residual volume (PVR) = 0 mL.
(B) X-ray obtained at VLPP shows contrast throughout the entire urethra.

detrusor overactivity and low bladder compliance can only be diagnosed with urodynamic studies.

Conclusions

Indications for urodynamics in men with LUTS depend upon the threshold of the clinician for obtaining the most accurate diagnostic information. The underlying pathophysiology of LUTS in men with BPH consists of urethral obstruction, impaired detrusor contractility, detrusor overactivity, and urgency. Accurate diagnoses can only be made with urodynamics, especially in cases where a surgical treatment is considered. Pressure–flow evaluation has been and remains the only “absolute way of diagnosing BOO” [1]. Although PFS has not been shown to predict responses to medical therapy, numerous studies have demonstrated that those patients with proven obstruction benefit more from prostatectomy than those who are not obstructed or have impaired detrusor contractility [9, 21]. Regardless, from a clinical viewpoint, videourodynamics serves no purpose unless the clinician bases their therapy on the results of the study, and urodynamics is only useful if detrusor overactivity and sensory urgency are treated differently from prostatic obstruction.

Notwithstanding these theoretic considerations, PFS is essential and videourodynamics preferable for men who have failed conservative and surgical therapies, particularly those considering more invasive treatment. Further, videourodynamics is recommended for men with known or suspected neurologic disease, including those with a history of spina bifida, diabetes mellitus, cerebral vascular accident, spinal cord injury, multiple sclerosis, Parkinson disease, and multisystem atrophy. Also, men with a history of major pelvic surgery or prior pelvic radiation and LUTS should undergo urodynamic evaluation.

Finally, even if videourodynamics were found to have no clinical import, it is still the best method of defining normal and abnormal physiology. Understanding physiology is the means by which new hypotheses are developed, leading to new research, new diagnostic methodologies, and, ultimately, new and more effective therapies.

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CHAPTER 121

Office-Based Cystoscopy: Continued Advances

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Introduction

Cystourethroscopic examination of the bladder and urethra remains the gold standard for the diagnosis of lower urinary tract disorders. It offers direct visualization of the bladder urothelium and provides initial access to the ureteral orifices for assessment and treatment of the upper urinary tracts. It is a cornerstone in the evaluation of gross and microscopic hematuria, and is useful in the investigation of lower urinary tract symptoms. Instruments passed through the cystoscope or specially-designed resectoscopes allow minimally invasive diagnosis and treatment of identified pathology. This chapter summarizes the role of cystoscopy (both rigid and flexible) as well as recent innovations in office cystoscopy.

Cystourethroscopy is performed using either rigid or flexible endoscopes. Endoscopes are measured with the French scale and are available in sizes to accommodate both pediatric (8–12F) and adult patients (16–25F). The French scale is equal to the diameter of the cylinder in millimeters multiplied by three, not the circumference as is sometimes thought. Increasing French units correspond to larger diameter endoscopes.

Rigid cystoscopy

Rigid cystoscopes are multicomponent instruments that consist of a sheath, an obturator, a bridge, and a telescope (Figure 121.1). The sheath provides a connection to the irrigation system. An obturator is placed through the sheath that aids entry into the bladder through the urethra. Most are hinged to allow a better angled approach past the male bulbar and prostatic urethra. Once inside the bladder, the obturator can be exchanged for a telescope with a bridge that allows for the passage of a variety of treatment implements (i.e. wires, stents, ureteral catheters, laser fibers). The light source connects directly to the telescope, which uses fiberoptic illumination and a rod–lens imaging system to transmit the light and image to the eyepiece. Various lens angles enable the endoscopist to evaluate adequately the entire urethra and bladder. The 0° lens allows the best view of the urethra, providing a straight image. This degree lens is many times the most useful in patients with urethral stricture disease. A 30° lens is used to visualize the trigone, posterior wall of the bladder, as well as the lateral side walls. It is the most commonly used lens in rigid cystoscopy. A 70–90° lens is often used to assess the dome and anterior bladder neck.

Spring-loaded resectoscopes are typically used for the resection of bladder lesions and prostatic hyperplasia. These implements are best used in conjunction with a 30° lens–rod system and require the use of a large-bore sheath (24–26F). Continuous flow irrigation, which utilizes an outer sheath with both inflow and outflow ports, prevents the bladder from compressing on itself during the procedure. This allows the area of interest,

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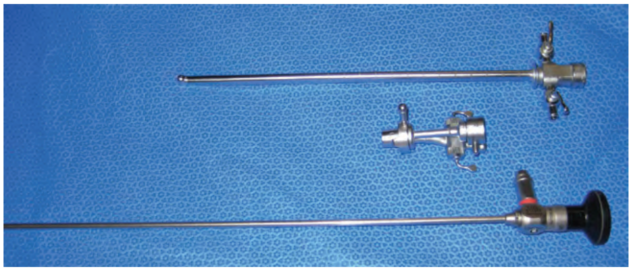

Figure 121.1 Basics of the rigid cystoscope (from top to bottom): metal sheath with inflow and outflow ports, bridge, and rod–lens system to which the light source it attached.

e.g. a bladder tumor, to remain fixed in space to facilitate resection. Continuous irrigation provides for more efficient resection and enhanced visualization, especially in the setting of transurethral resection of the prostate (TURP).

Rigid cystoscopes provide a relatively large working port to accommodate a variety of accessory instruments. This is a major advantage; however, the large size of the rigid cystoscope decreases its applicability in males unless general or regional anesthesia is utilized. Additionally, patients must be placed in the dorsal lithotomy position to facilitate an adequate examination. Rigid cystoscopy, therefore, is difficult to perform in the male patient outside of the modern operating room.

Procedures

Rigid cystoscopy is utilized to assess the bladder and upper urinary tracts for diagnostic evaluation of multiple clinical entities, such as hematuria, voiding complaints, and urothelial carcinoma. Retrograde imaging of the ureter and renal pelvis can be accomplished with the use of contrast injected through small catheters passed into the ureteral orifice under cystoscopic guidance. Ureteral stents are commonly inserted via the rigid cystoscope. Upper tract access for ureteroscopy may also be established with the use of wires and open-ended catheters. After wire passage has been confirmed with the use of fluoroscopy, the rigid cystoscope may be exchanged for a ureteroscope. Other uses are possible but have been largely supplanted with flexible cystoscopy.

Technique

After obtaining informed consent and verifying proper instrument sterilization and availability, the patient should be prepped and draped in a standard sterile fashion. In both male and female patients, lubricant jelly should be instilled into the urethra before the procedure. If the meatus or urethra is unable to comfortably accommodate the cystoscope, dilation should be performed. This can be accomplished with the use of urethral sounds in a serial fashion. The urethra should be dilated to a diameter of at least 2 French units greater than the instrument (e.g. dilate to 26F if utilizing a 24F cystoscope).

In the male, the penis should be grasped and straightened as the endoscope is introduced to allow for inspection of the fossa navicularis and the anterior urethra. As the scope traverses the anterior urethra, the examiner's hand should be depressed to bring the penis parallel with the floor. This allows for examination of the membranous urethra and prepares the examiner to view the prostatic urethra. The verumontanum is noted when the examiner reaches the prostatic urethra. The prostatic lobes are seen laterally at this point in the examination. When the bladder neck is in view, it is often necessary for the examiner to depress the endoscope by dropping their hand toward the floor so as to account for the gentle upward angulation encountered before entering the bladder [1].

Once the endoscope is inside the bladder, a systematic evaluation of the entire bladder surface is performed in a routine and reproducible fashion. The trigone is the first landmark encountered when visualizing the bladder with a 30° lens. The examiner should follow the trigone laterally to identify the ureteral orifices effluxing clear urine. Next, attention should turn towards examination of the bladder floor beyond the trigone and the posterior wall. The lateral walls are then carefully inspected by rotating the lens side to side. The dome and anterior bladder wall are best viewed with the 70° lens. The scope should be rotated 180° to facilitate this part of the procedure, paying close attention to keeping the camera head level (if one is being utilized). The air bubble serves as the landmark for the dome. It is often necessary to apply pressure just superior to the pubic bone when visualizing the anterior bladder neck.

Flexible cystoscopy

Flexible cystoscopy of the urinary tract is a fairly recent phenomenon. In 1973, Tsuchida and Sugawara reported utilizing a flexible "fibercystoscope" for examination of the bladder neck [2]. Since the development of the first purpose-built flexible cystoscope in 1984, flexible fiberoptic cystoscopy has become an accepted diagnostic and therapeutic modality, and today is the most commonly performed in-office procedure by the practicing urologist. The development of working ports, smaller cystoscope diameter with preserved image quality, active deflection, and most recently digital cystoscopes, have greatly enhanced the ability of the user to apply flexible cystoscopy for a variety of diagnostic and therapeutic applications. When compared to rigid cystos-

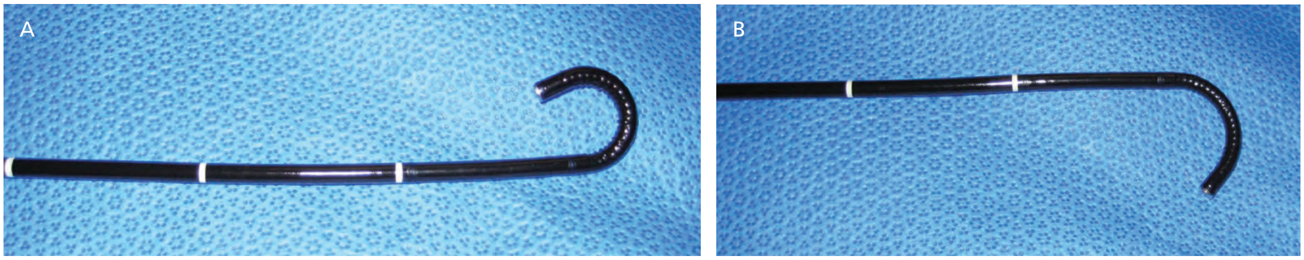

Figure 121.2 (A, B) Tip of the flexible endoscope can be deflected 180–220° to allow visualization at nearly any angle.

copy, flexible cystoscopy is more comfortable for patients and can be performed with only local anesthesia. The deflection capabilities of the flexible cystoscope allow for easier passage through the bladder neck, as well as superior visualization of the anterior bladder wall (Figure 121.2).

However, there are disadvantages to flexible cystoscopy. Flexible endoscopes are costly and require more delicate care when compared to rigid cystoscopes. These instruments have smaller irrigating ports and lack a separate working sheath. As a result, changing lenses, assessing residual urine and repeat evacuation of irrigant and/or urine cannot be completed without entirely removing the endoscope or actually withdrawing gradually contents via the single, small-caliber channel of the irrigation port.

Simply by its nature, the image obtained from a flexible fiberoptic cystoscope is inferior when compared to the rod–lens system employed in rigid cystoscopy. Fiberoptic technology has distinct imaging limitations owing to the finite diameter of the image-carrying glass fibers that make the pixelated "screen door" effect insurmountable [3]. There are generally three fiberoptic bundles within the shaft, two for light and one for the image. The image obtained by the fiberoptic bundle is a composite matrix of each individual fiber in that bundle, analogous to a newspaper photograph in which multiple dots merge into a single reconstructed image. Digital endoscopy, as discussed below, is able to overcome the limitations of fiberoptic endoscopy.

Procedures

The single most common indication for flexible cystoscopy is evaluation for hematuria, whether gross or microscopic. Visualization of the entire urethra and bladder can be accomplished efficiently and without significant discomfort. Other diagnostic applications include its use in the evaluation of male or female voiding dysfunction. Flexible cystoscopy, however, is not indicated in the routine evaluation of male voiding dysfunction thought to be attributed to outlet obstruction from benign prostatic hyperplasia (BPH), as the endoscopic appearance of the prostatic urethra and bladder does not predict the response to BPH therapy [4]. However, endoscopic assessment is appropriate and often necessary in men being considered for surgical therapy of outlet obstruction to rule out the presence of urethral stricture or bladder neck contracture, especially in those individuals who have undergone prior transurethral surgery. It is essential as well to evaluate any suspected anatomic abnormalities.

In addition to diagnostics, there are many therapeutic office-based applications. These include the injection of urethral bulking agents for stress urinary incontinence and intravesical injection of botulinum toxin for voiding dysfunction. Removal of ureteral stents or of foreign bodies is another commonly employed procedure that is made safe, efficient, and reliable with the use of modern flexible cystoscopy. This can be done with grasping forceps, a retractable lasso device, or four-pronged grasping forceps with a retractable sheath. Once the cystoscope is introduced into the bladder and the object is identified, the grasping device is passed down the working channel and into the field of view. The object is then firmly grasped and the endoscope and graspers are removed as a unit under direct visualization.

Suspicious lesions in the bladder may be sampled in the office setting with the use of flexible biopsy forceps and electrocautery. When biopsies are to be obtained, a topical anesthetic agent (lidocaine 1% solution) is instilled into the bladder and left in place for 10 min prior to the procedure. An electrocautery unit and probe must be readily available in this situation. A nonconductive solution such as water or glycine must be the irrigant when electrocautery is used. Laser fulguration of small lesions is possible and is becoming increasingly used. This option is especially useful in patients with known rapidly recurring, low-grade, papillary tumors of the lower urinary tract.

Technique

The patient should be prepared in a fashion analogous to that for rigid cystoscopy. In both male and female patients, lubricant–anesthetic gel should be instilled into the urethra before the procedure. A recent meta-analysis has demonstrated that subjects who received anesthetic-impregnated gel were 1.7 times more likely not to experience moderate-to-severe pain than subjects who had no intraurethral anesthetic instillation [5].

Examination of the urethra and bladder with the flexible cystoscope is performed in a slightly different manner from rigid cystoscopy. The anterior urethra can be viewed in a retrograde manner. The prostatic urethra should not be examined during retrograde passage of the endoscope as it will often appear obstructed. Instead, the prostatic urethra should be examined antegrade as the endoscope is being withdrawn from the bladder [6].

As with rigid cystoscopy, the bladder should be examined in a predetermined systematic fashion that the examiner can reliably duplicate to ensure adequate examination of its full contour. A standardized approach also aids in reliable documentation. The bladder should be cleared of turbid urine, clot, and debris prior to examination. The bladder is then filled with a sufficient volume to allow distention of mucosal folds. The bladder does not have to be distended as much as in rigid cystoscopy for adequate visibility. The first landmark in the bladder that is often seen is the air bubble at the dome. One systematic approach then is to evaluate the bladder by starting along the 12 o'clock position by pulling the endoscope toward the bladder neck and along the midline until the bladder neck is just entered. The endoscope is then returned to the dome and rotated from the 12 to the 4 o'clock position, and then from the 12 to the 8 o'clock position in a counter-clockwise fashion. Next the scope is returned to a neutral position. The scope is then deflected to the six o'clock position to view the trigone. The 5, 6, and 7 o'clock positions are examined as previously described.

Advances in office cystoscopy

The use of video cameras in endoscopy was introduced in 1956 by French researchers [3]. This development enhanced ergonomics, safety, and success rate for pathologic findings. This approach has many advantages, including the avoidance of contact with body fluids, patient education, and documentation through the use of digital camera technology [1].

Videoendoscopy with flexible scopes allows patients to visualize normal and abnormal anatomy, and thus helps them to understand their pathology. In male patients, videocystoscopy utilizing a monitor has been shown to produce a 40% decrease in the pain and discomfort level compared to those who did not view the procedure on the monitor [7].

Recently, the key advance in office cystoscopy has been the continued improvement and innovation in the visualization mechanism. Digital (distal sensor) endoscopy based on CCD (charge-coupled device) and CMOS (complementary metal oxide semi-conductor) chips has recently been introduced into the field of endourology. Digital sensors are composed of millions of photodiodes which convert photons into electric current that is later transformed into voltage, amplified, and converted to a digital form [3]. On both types of chips, the information is transferred to a controller box for image presentation or storage (i.e. the box that is connected to the cystoscope).

Distal sensor cystoscopes based on these technologies were introduced in an effort to provide urologists with better optical resolution, contrast, color differentiation, and improved durability. Digital image capturing allows for plug-and-play capability. Contemporary digital sensor endoscopes are able to meet the size requirements of flexible cystoscopy. They are already superior to flexible fiberoptic endoscopes in terms of weight and are thus easier to handle during procedures. Additionally, distal sensor cystoscopes do not require white balancing and camera focusing. *In vitro* evaluation has demonstrated that distal sensor cystoscopes are superior to fiberoptic cystoscopes in terms of resolution, contrast discrimination, and red color differentiation [8].

The first commercial digital flexible endoscope was the ACMI DCN-2010 introduced in 2005 (ACMI, Southborough, MA, USA). Quayle *et al.* compared this cystoscope with three contemporary fiberoptic scopes and found the digital scope to provide superior optics [9]. Okhunov *et al.* conducted a prospective clinical comparison of distal sensor (digital) and fiberoptic cystoscopes in over 1000 patients who underwent office-based cystoscopy. All surgeons found the digital sensor endoscopes to be lighter and easier to handle. Both subjective optical and functional metrics were significantly better with the distal sensor cystoscopes. Substantial differences were found with cystoscope deflection when instruments were placed in the working channel; however, the evaluating surgeons did not believe that this diminished function. Finally, both the fiberoptic and digital cystoscopes proved durable with a 0.2% repair rate during the study period [10]. It remains to be seen if distal sensor technology will ultimately prove cost-effective.

Another technology that might prove useful in office-based cystoscopy is narrow-band imaging (NBI), which is made possible by the CCD chips. This narrrow bandwidth of light (415 and 540 nm) is strongly absorbed by hemoglobin and penetrates only the surface of tissue. By narrowing the bandwidth of light from the flexible cystoscope, NBI improves the definition of the epithelial surface and emphasizes the mucosal microvessels. NBI has demonstrated superior sensitivity for identifying recurrent flat and papillary superficial bladder tumors in a surveillance setting when compared with standard white light cystoscopy. This technology was not studied for the more difficult to detect lesions, such as carcinoma *in situ* [11].

Conclusions

As technology continues to evolve, office-based cystoscopic procedures continue to improve and expand. The ability to utilize flexible cystoscopy in an increasing number of clinical situations has benefitted both physicians and patients. At the same time, it continues to be the standard diagnostic evaluation tool for the practicing physician.

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PART 2 Office/Ambulatory Set-up for Minimally Invasive Treatment of the Prostate

CHAPTER 122

Equipment Set-up and Patient Handouts

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Introduction

Team collaboration and communication are essential to successful endourologic procedures. The entire staff must be thoroughly familiar with the equipment and instrumentation needed for specific procedures; they must ensure that instruments are functioning properly to avoid delays, and that the operating room (OR) set-up meets the surgeon's specifications. In this chapter, we describe the responsibilities of the urology nursing team for setting up the equipment, instrumentation, and supplies, and for organizing the OR for lower urinary tract endoscopy and vaginal surgery.

Operating room set-up

The necessary equipment should be assembled in the OR suite and its function assessed before the patient enters. The OR set-up should accommodate at least one (preferably two) table set-ups, the OR table, endoscopic video cart (Figure 122.1), anesthesia equipment, laser unit, electrosurgical unit, computer station, and, preferably, C-arm fluoroscopy. Space for the latter is preferable since the same room will usually also be used for various fluoroscopic procedures (e.g. ureteral stenting, ureteroscopy, percutaneous renal interventions). In addition, there must be adequate room to set up equipment, move about freely, assist the anesthesiologist, and perform documentation. There must be ready access to the two-way telephone.

Modern ORs are equipped with ceiling-mounted boom arms for housing various surgical and anesthesiologic equipment (Figure 122.2). The boom arms provide ergonomic advantage in moving various equipments perioperatively. Video monitors can be placed as per the surgeon's/assistant's individual requirement to minimize neck strain. Additionally, the use of boom arms means there will be fewer cables and trolleys occupying the floor space, making movement better and faster, and assisting with cleaning. Studies have shown small but significant advantage of boom arms over conventional cart system in terms of anesthesia preparation time and surgical procedure preparation/turnover time, especially in laparoscopic surgery [1–3]. Three boom arms are generally required to house all suspendable items. However, boom arm systems do have disadvantages: they are significantly more expensive than floor carts; the minimum height and width requirements of the OR are more stringent; equipment that needs to be moved in and out of the OR cannot be placed on the boom arms; and there may be the hazard of equipment collision and arm malfunction/disconnection. Nevertheless, with advancing technology, the boom arm system seems here to stay.

The recommended size of a fully functional endourologic OR is 23 × 23 square feet floor and 12-feet high false ceiling; a 2-feet gap above the ceiling is used to accommodate cables, wires, pipings, and air conditioning vents [4]. The floor design of an endourologic OR is of paramount importance for hygienic and efficient

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drainage of fluids that are part and parcel of endourology practice. It is recommended that there is a drain in the center of the OR with a slight slope of the floor towards it from all the walls [4]. In the absence of such a drainage system, a powerful active suction device should be available for suction of fluids directly from the patient drapes (Neptune Waste Management System, Stryker®, Kalamazoo, MI, USA).

There should be ample room for storage of instruments, equipment, and consumables both within the OR and in a central storage place close to the OR. Typically, a modern OR has storage shelves flush mounted in the OR walls and sealed with sterile jointing system.

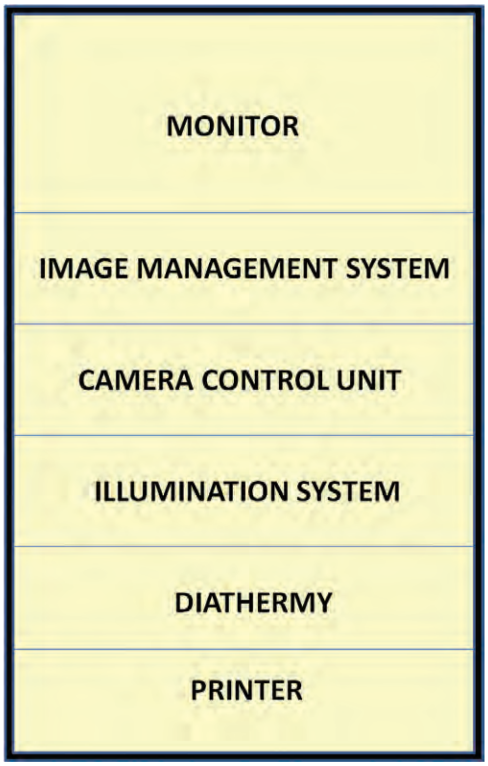

Figure 122.1 Set-up of an endoscopic video cart for lower tract endoscopy.

Lighting

It is important to have an appropriate level of lighting throughout the OR and this will differ in different places. The sterile area must have at least 1500 Lux and rest of the room 500 Lux of light intensity. The recommendation for operating area lights is a shadowless white light as high as 3×10^5 Lux at 1-m distance for a twin-dome system. The modern operating area lights are predominantly of two types; halogen and more recently, LED (light emission diode); the latter provide high-quality cold white light and are more durable than

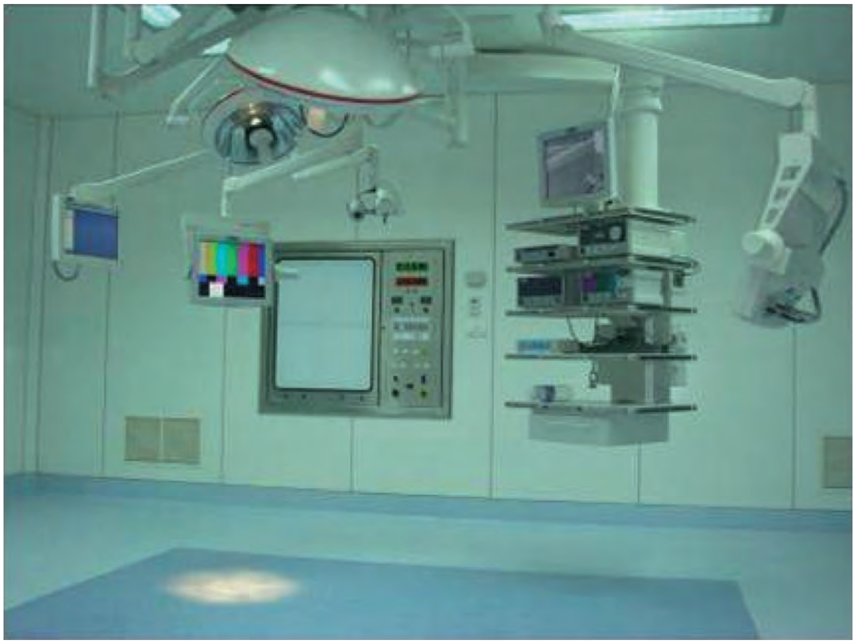

Figure 122.2 Operating room set-up on boom arms. Note the absence of cables, wires, tubings and carts on the floor.

the former. The operating area lights are mounted on boom arms and should have free vertical as well as horizontal mobility. Regulation of lighting level (graded dimming, on–off) is also important during a case. The various lighting controls should be available to the surgeon in the sterile field (touch screen monitor) as well as on a conveniently placed OR control panel. The latter can also regulate the clock, timer, temperature, and humidity.

Operating room table

The patient table must be made of rust-proof stainless steel. It should be easily movable on built-in wheels with central locking. To accommodate a large variety of surgical procedures, it should consist of separable head and leg sections, and have the facility for attachment of various stirrups for lithotomy position and attachment of a collection device (either ring or basin), and preferably a gynecological cut-out at the tail end of the body section. It should be capable of various positions (up/down, Trendelenburg/reverse Trendelenburg and lateral tilt). The controls for positioning the table should be available on a remote control (and also preferably on a touch screen monitor accessible to the surgeon). The table should be radiolucent and have an eccentrically placed base to accommodate a C-arm intensifier for intraoperative use of fluoroscopy.

Documentation

Archival of patient-related data for later referral and follow-up is important not only for clinical management, teaching and research, but is also a legal requirement for medicolegal purposes. Archival is performed in the physical form and/or electronically. Electronic record keeping has been available for decades and continuing advances in information technology have led to more widespread use of convenient and comprehensive archiving of text as well as graphic, image, and video data. The advantages of electronic archival are more complete archival, and more accurate and comprehensive recall. Moreover, much less space is required.

Hospital Information System is the most widely used electronic archival system and is used to manage hospital administrative, financial, and clinical records. It works using the Health level seven (HL7) protocol. In medical imaging, electronic picture archiving and communication systems (PACS) have been developed in an attempt to provide economic storage, rapid retrieval of images, access to images acquired with multiple modalities, and simultaneous access at multiple sites The universal format for PACS image storage and transfer is DICOM (Digital Imaging and Communications in Medicine). Nonimage data, such as scanned documents, may be incorporated using consumer industry standard formats like PDF (Portable Document Format), once encapsulated in DICOM. A PACS consists of four major components: imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), a secured network for the transmission of patient information, workstations for interpreting and reviewing images, and archives for the storage and retrieval of images and reports.

In the modern OR, there should be an electronic workstation located in one corner. The workstation has inputs from various audiovisual devices in the OR (e.g. cameras – endovision, overhead, room camera; C-arm; ultrasound, etc.). It also has a computer connected to the HIS and PACS for ready referral to archived data and input of new data.

Another important aspect of a modern OR is the ability to relay audiovisual information (images, live video) to various places, e.g. the surgeon's office, lobby, and auditorium. Most surgical meetings devote a major session to the live operative workshop. Often, live transmissions are performed by erecting temporary facilities, which involves high cost without providing optimal quality. If the transmission facilities are frequently used either for conference workshops or teaching, then it makes sense to install these facilities during construction of the OR. Once the cabling is installed, there are no recurrent cost and, in the long run, this is economic (Figure 122.3).

Integration of the operating room

In the last few years it has become clear that the OR of the future needs to be integrated to optimize space, efficiency, and intraoperative decision-making. The surgeon's working environment has already undergone drastic changes, especially with the popularity of minimally invasive techniques in surgery. The development of these techniques and other technologies have made the OR suite progressively more complex and more difficult to manage.

A centralized OR with sterile controls minimizes this complexity by integrating minimally invasive surgical equipment, X-ray, ultrasound, video recorder, telephone, video printer, MRI, and other components, so that the nurse and surgeon can operate the components from a single interface.

Set-up for a surgical procedure

A number of procedures can be performed via the retrograde transurethral portal of entry, e.g. cystoscopy (CPE), transurethral resection of bladder (TURBT) or prostate (TURP), visual internal urethrotomy (DVIU), and various laser procedures on the prostate or bladder,

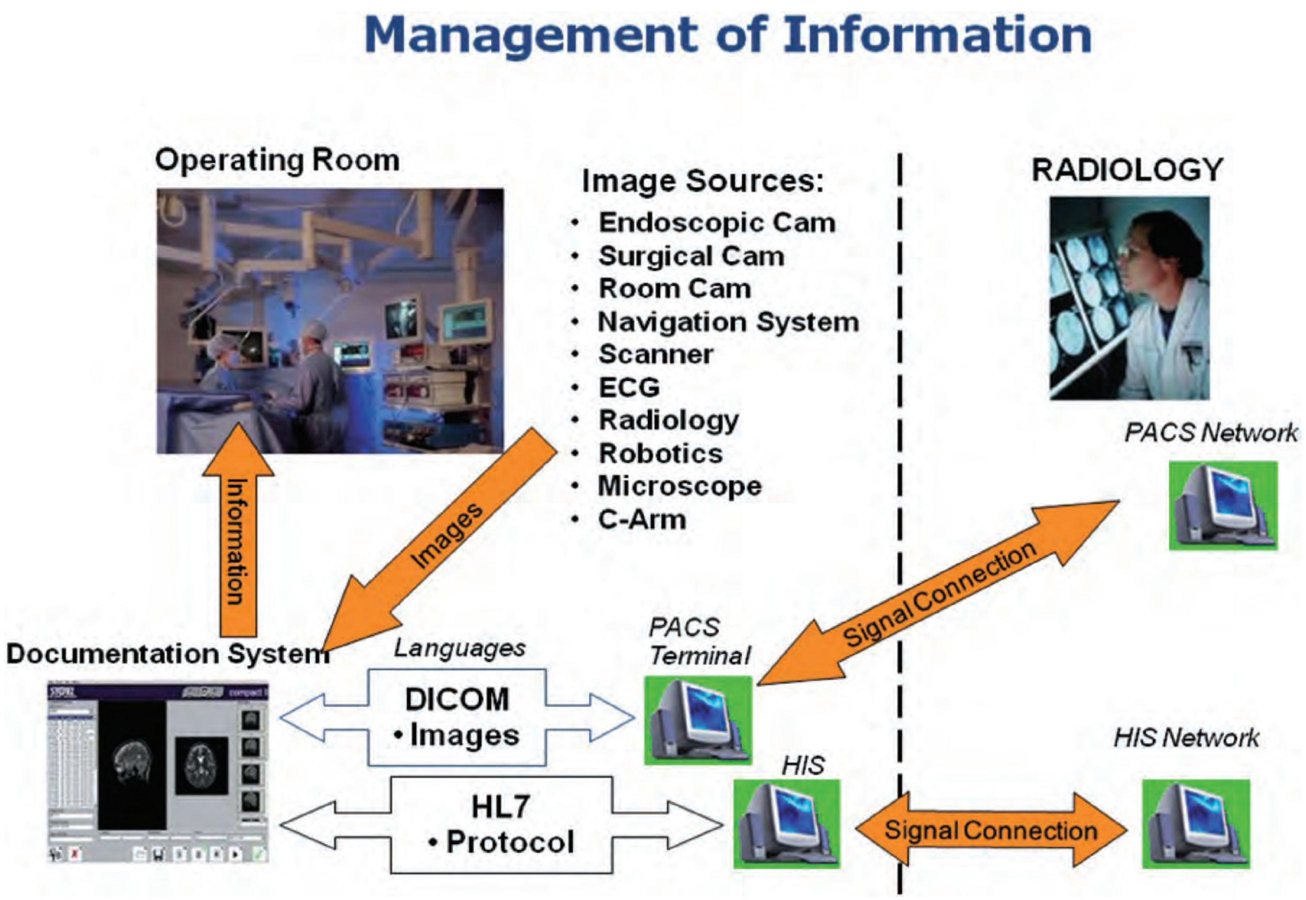
Management of Information
Operating Room
Image Sources:
• Endoscopic Cam
• Surgical Cam
• Room Cam
• Navigation System
• Scanner
• ECG
• Radiology
• Robotics
• Microscope
• C-Arm
RADIOLOGY
PACS Network
Information
Images
Signal Connection
Documentation System
Languages
PACS Terminal
DICOM
• Images
HL7
• Protocol
HIS
HIS Network
Signal Connection

Figure 122.3 Data management in a modern operating room.

etc. For most procedures, two nurses are optimally required for set-up and smooth functioning during the case. Endourologic instrumentation and equipment will vary depending on the operative procedure.

With current advances in the understanding of the pathophysiology of urinary incontinence and pelvic organ prolapse, most of these can be managed through the vaginal route with/without use of graft material. Similarly, prostheses are increasingly being placed for urinary incontinence (artificial urinary sphincter) and for erectile dysfunction (inflatable or malleable penile prosthesis). The OR therefore should be equipped to tackle all these procedures.

The scrub nurse is responsible for setting up the instrument-table; to ensure that the instruments are adequately sterilized as per protocol; all instruments, telescopes, and accessories (electrosurgical unit, laser, light source, suction, etc.) are working properly; and everything on the table is neatly arranged and connected for easy availability. It is advisable to have some sort of a check-list so that "nothing" is missed. The scrub nurse is assisted in this process by the circulating nurse. While the scrub nurse is preparing the sterile set-up, the circulating nurse reviews the patient's chart. The circulating nurse acts as the patient's advocate, reviewing the OR sequence with the patient, identifying the correct operative site and laterality, addressing any concerns the patient may have, and communicating with the patient's family.

Antibiotics and prophylaxis against deep vein thrombosis (DVT) must be available if indicated. The availability of blood products for possible transfusion should be checked before the circulating nurse brings the patient into the OR.

After the anesthesia, the patient is usually placed in the lithotomy position. This is the most commonly employed position, although some procedures can be performed in the supine position (e.g. penile prosthesis). The patient's legs are raised slowly and simultaneously by two team members and positioned in gel-padded foot-rest stirrups (Figure 122.4), and the buttocks are extended over the table edge. Precautions must be taken to prevent pressure on the peroneal, saphenous, posterior tibial, popliteal, and sciatic nerves. Flexion, extension, and compression due to incorrect positioning of the legs can result in nerve damage, venous thrombosis,

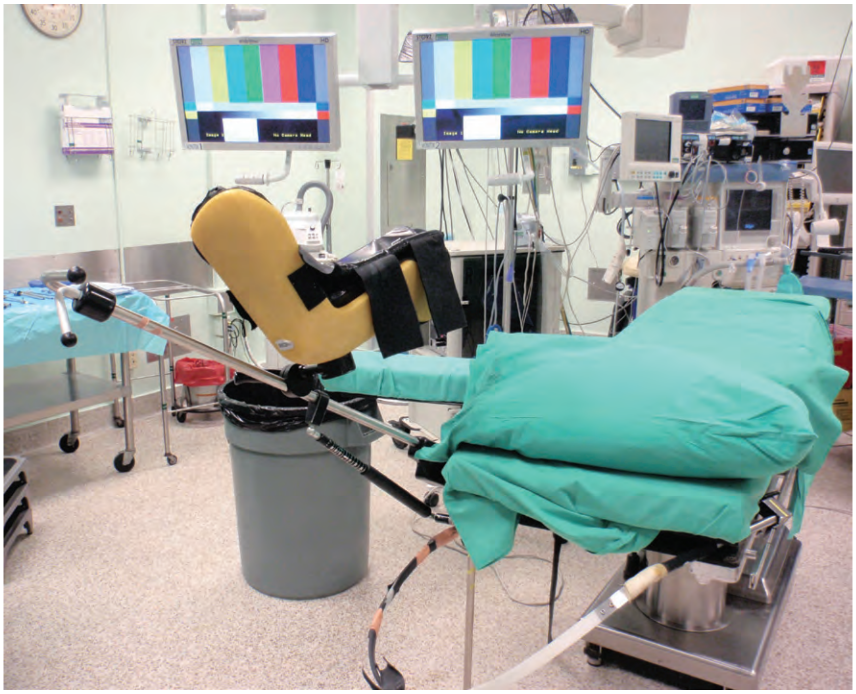

Figure 122.4 Allen Yellofin™ lithotomy stirrup (Allen Medical System, Leicester, UK). Note the ergonomic positioning of the monitors (hung from the spring arm).

compartment syndrome, and hip-joint dislocation. For a lengthy procedure, antiembolic stockings and compression sleeves are used. Both arms should be secured on padded arm boards to prevent injury to the patient's fingers or hands when the table is raised or lowered.

Once the patient is positioned, a patient plate is fixed distant to bony prominences for use with monopolar diathermy. After removal of any visible contamination, the minimum necessary clipping of hair is performed with an electric clipper; this may even be omitted in certain circumstances. Shaving of hair is not recommended, nor is part preparation before coming to theater, since there is a proven association with increased risk of infection [5]. Next, skin preparation is done using antiseptic solutions; the iodophors (e.g. povidone–iodine), alcohol-containing products, and chlorhexidine gluconate are the most commonly used agents. A recent randomized controlled study concluded in favor of 2% chlorhexidine gluconate and 70% isopropyl alcohol compared to 10% povidone–iodine for preventing superficial and deep surgical-site infections in clean–contaminated surgery [6]; we typically use the former for the same (Chloraprep®; CareFusion, El Paso, TX, USA). With the apprehension of infection associated with prosthetics (e.g. artificial urinary sphincter, penile prosthesis), it is common practice to manually scrub the parts using povidone–iodine or chlorhexidine for 10 min after positioning the patient.

Transurethral surgery

After standard draping, attachments for collection of irrigant fluid/tissue must be ensured before starting the procedure. Various proprietary drapes are available with inbuilt collection systems (Kimberly-Clarke®, Reigate, Surrey, UK; Microtek Medical, Columbus, MS, USA; G Surgiwear, Shahjahanpur, UP, India). Commonly, the outlet of the collection device is attached to a large dual-suction device in order to prevent spillage.

A typical set-up for transurethral resection is described below.

Equipment

This consists of one back table for the set-up, one prep table, one single-ring stand, energy generator (monopolar, bipolar, laser), and vision tower.

Instrumentation

This consists of a camera system, telescopes, urethral sounds (Vanburen), a cystoscopy tray, and a resectoscope tray (separate for monopolar, bipolar, laser).

Set-up

This consists of an open prep tray on the prep table, a disposable cystoscopy pack on the back table, and a cystoscopy basin on a single-ring stand.

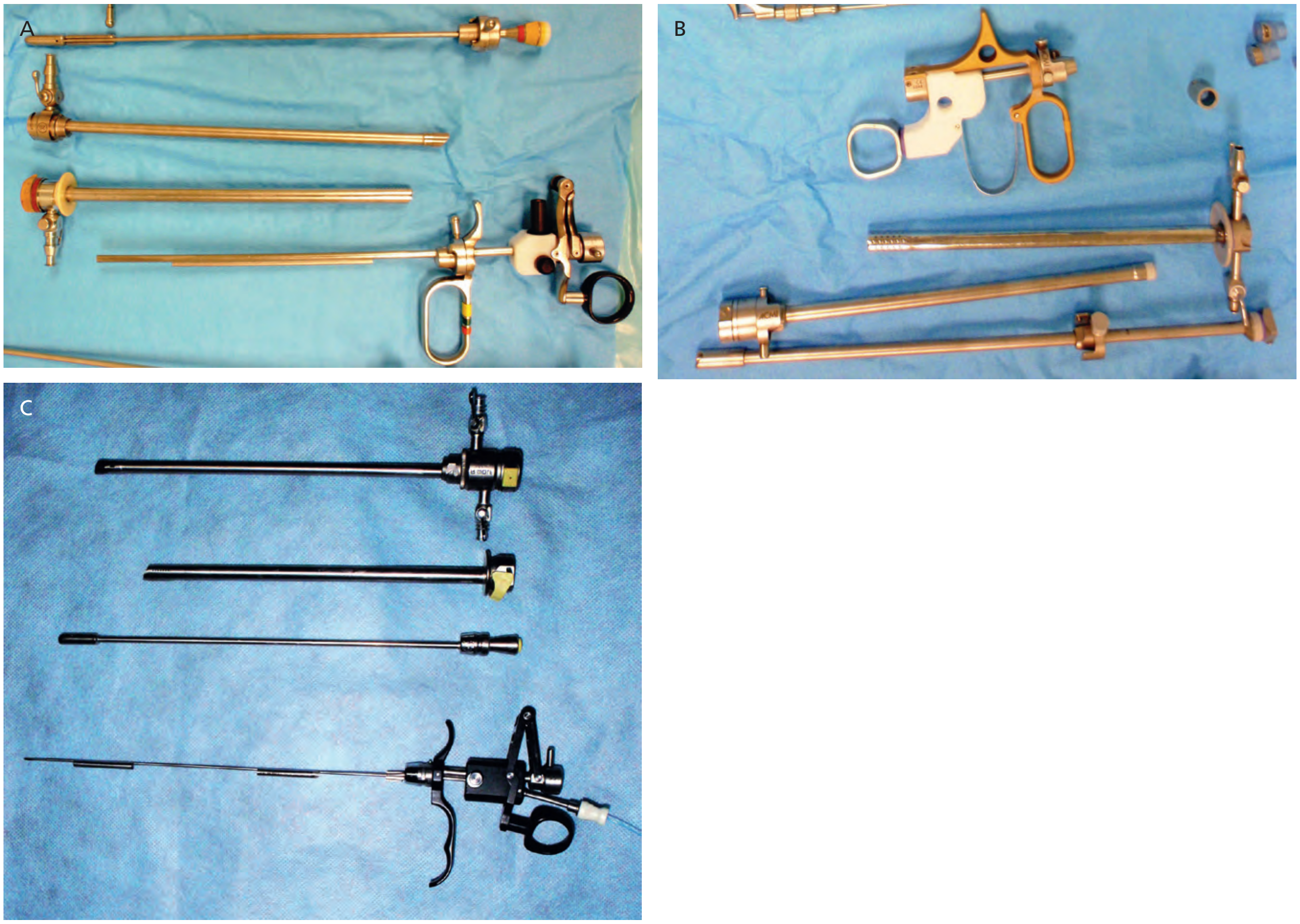

Figure 122.5 Resectoscopes: (A) monopolar (Karl Storz, Tuttlingen, Germany); (B) bipolar (Gyrus-ACMI, Southborough, MA, USA); and (C) Holmium laser (Richard Wolf, Knittlingen, Germany). All resectoscopes have similar components, i.e. outer sheath, inner sheath, deflecting tip obturator, working element.

Back table

The cystoscopy pack consists of a back table drape, patient drapes, irrigation "Y" tubing/TUR set, k-y jelly, a marker pen and labels for labeling fluids, a 10- and 20-mL syringe, a Telfa pad (Kendall, Covidien, Mansfield, MA, USA) for specimens, a disposable graduate, two small basins, and three disposable towels.

Prep table

The scrub nurse will set up the prep table with five sponges for prepping the patient and place another five sponges on the cystoscopy table for use on it. Patient drapes are placed in the left lower corner of the back table. All cords to be passed off are placed in the left upper corner of the back table (camera, light cord, cysto "Y" tubing, Bovie or bipolar cord). A towel with k-y jelly on it is placed beside the drapes. The Vanburen sounds are then placed in sequential order from smallest to largest. Next, the 22F cystoscope sheath and obturator, 0° telescope, 30° telescope with double channel bridge attached, and 70° telescope with single channel bridge attached are placed. Next to these the resectoscope set is placed, which consists of (Figure 122.5):

- *Monopolar resection*: continuous flow resectoscope set 26F/28F: outer sheath, inner sheath, visual obturator with single channel, Timberlake deflecting tip obturator, passive type/active type (surgeon's preference) working element for the resectoscope, and disposable loop (of the surgeon's choice for resection). A Toomey syringe/Ellik's evacuator is also placed to use at the end of the case for irrigating the bladder and evacuating any specimen from the bladder. 1.5% Glycine is the irrigating fluid of choice for monopolar resection, and 0.9% normal saline for continuous irrigation postoperatively. Adequate amounts of both must be available for an uninterrupted procedure.
- *Bipolar resection*: Gyrus PK® Superpulse® (Gyrus ACMI, Southborough, MA, USA) has been the most extensively studied and is the most widely used generator. (The set specific to this manufacturer includes a

25.6F/27.6F inner and outer sheath, visual sheath, Timberlake obturator, Iglesias working element, and disposable loop. 0.9% Normal saline is the irrigant of choice for this procedure. Bipolar set-up confers certain advantages: lower incidence of dilutional hyponatremia by virtue of using normal saline rather than glycine for irrigation, and less scatter of current (decreased incidence of obturator jerk and safe in patients with a pacemaker).

- *Laser resection*: holmium:YAG and KTP are commonly used lasers for prostate diseases. The resectoscopes/cystoscopes for these are different from the above as well as from each other. The basic set has similar components (i.e. outer sheath, inner sheath, obturator, working element), but their working elements have specially designed working channels to accommodate the laser fiber.

Penile prosthesis

Equipment

This consists of one prep table, one back table, two Mayo trays, two double-ring stands, and an electrosurgical unit.

Instrumentation

This consists of a urology minor tray, penile prosthesis tray, and a cantilevered retractor.

Supplies

These include one 10-mL syringe, three 20-mL syringes, two 60-mL syringes, one 14F Foley catheter and urine drainage bag, one Steri-Drape, a Lone Star retractor with hooks, a dilamezinsert inserter, a #15 surgical knife blade, a needle protector, a marker pen and labels for medication, a pencil for monopolar diathermy, bipolar diathermy forceps, and suction tubing. It is of paramount importance to ensure all components of the prosthesis are available in various sizes in the OR before the patient is brought into the OR.

Set-up

This consists of an open prep tray on the prep table, an open major pack (table cover, five half sheets, two wet-proof drapes, 12 towels, one Mayo tray cover, two wet-proof towels, and four gowns) on the back table, an open major basin set on each ring stand, one extra half-sheet, and one extra Mayo tray cover.

Circulating nurse

The circulating nurse must ensure the patient has received appropriate antibiotics when they come into the OR, and have appropriate antibiotics ready to place on the sterile field for irrigation when the scrub nurse is ready. They must record all items used on the room record and fill out all appropriate implant documentation. For DVT prophylaxis we always place sequential compression devices on the patient prior to induction of anesthesia.

Scrub nurse

The table is set up in the usual way. Instruments from penile prosthesis tray are placed in an extra rectangular basis and soaked in antibiotic solution (Hegar dilators, nasal speculum, measuring device, dilamezinsert, furlow tool, and quick connect device). Both Mayo trays are draped in the usual fashion; in addition, one of these is also draped with an impervious Steri-Drape. A small round basin, a large round basin, and a rectangular basin, along with all the syringes are placed on this Mayo tray (this is the prosthesis Mayo and anything placed on it should be rinsed in sterile water beforehand). The small basin is used to keep rubber-shod mosquito clamps, the large basin for plain 0.9% normal saline to fill the device with, and the rectangular basin to place the device for preparation. The 10-mL syringe is used for the Foley catheter, the 20-mL syringes for flushing the prosthesis tubings, and the 60-mL syringes to fill the device and reservoir. The four major basins should be filled with sterile water and two are placed on each side of the patient for the resident and surgeon to use to wash and rinse the blood from their gloves prior to handling the prosthetic device. Normal saline on the field will have antibiotics placed in it for irrigation (except as stated on the prosthesis Mayo). On the other Mayo (nurse's Mayo) there should be Adson forceps, short DeBakey forceps, suture scissors, metzenbaum scissors, four straight hemostats, four curved hemostats (all of which are used to tag closing stitches placed in the corpora prior to placing the prosthesis), one Allis clamp, and one Lahey dissector.

Device preparation

Preparation will depend on the type of device and the manufacture's guidelines.

Artificial urinary sphincter prosthesis

The set-up is more or less similar that for a penile prosthesis. The supplies should include a ¼-inch Penrose drain (to place around the urethra), kittners (to assist with dissecting around the urethra), and methylene blue if needed to test for urethral integrity. Hegar dilators, nasal speculum, measuring device, dilamezinsert, furlow tool, and quick connect device are not required.

Vaginal surgery (e.g. mid-urethral sling, cystocele repair)

The OR set-up described above is sufficient for vaginal surgery as well. Specifically, the table must have a gyne-cut to allow space for the vaginal speculum/retractor, and the lithotomy poles must be capable of full/extended lithotomy. In addition, certain special instruments, e.g. weighted vaginal retractor, Lone Star retractor, Breisky–Navratil vaginal retractor, Sim's speculum, Stamey needles, Heaney curve-tipped needle holders, and Mueller S-shaped dissecting scissors, etc., may be useful (Figure 122.6).

Equipment

This consists of one prep table, one back table for set-up, two Mayo trays, one double ring stand, one Bovie, and one video tower.

Instrumentation

This consists of a urology minor tray, sling specials, and a cantilevered retractor, and towards the end of the case, a cystoscopy set (instruments, telescopes and camera). Instruments used include toothed forceps, short DeBakey forceps, suture scissors, Metzenbaum scissors,

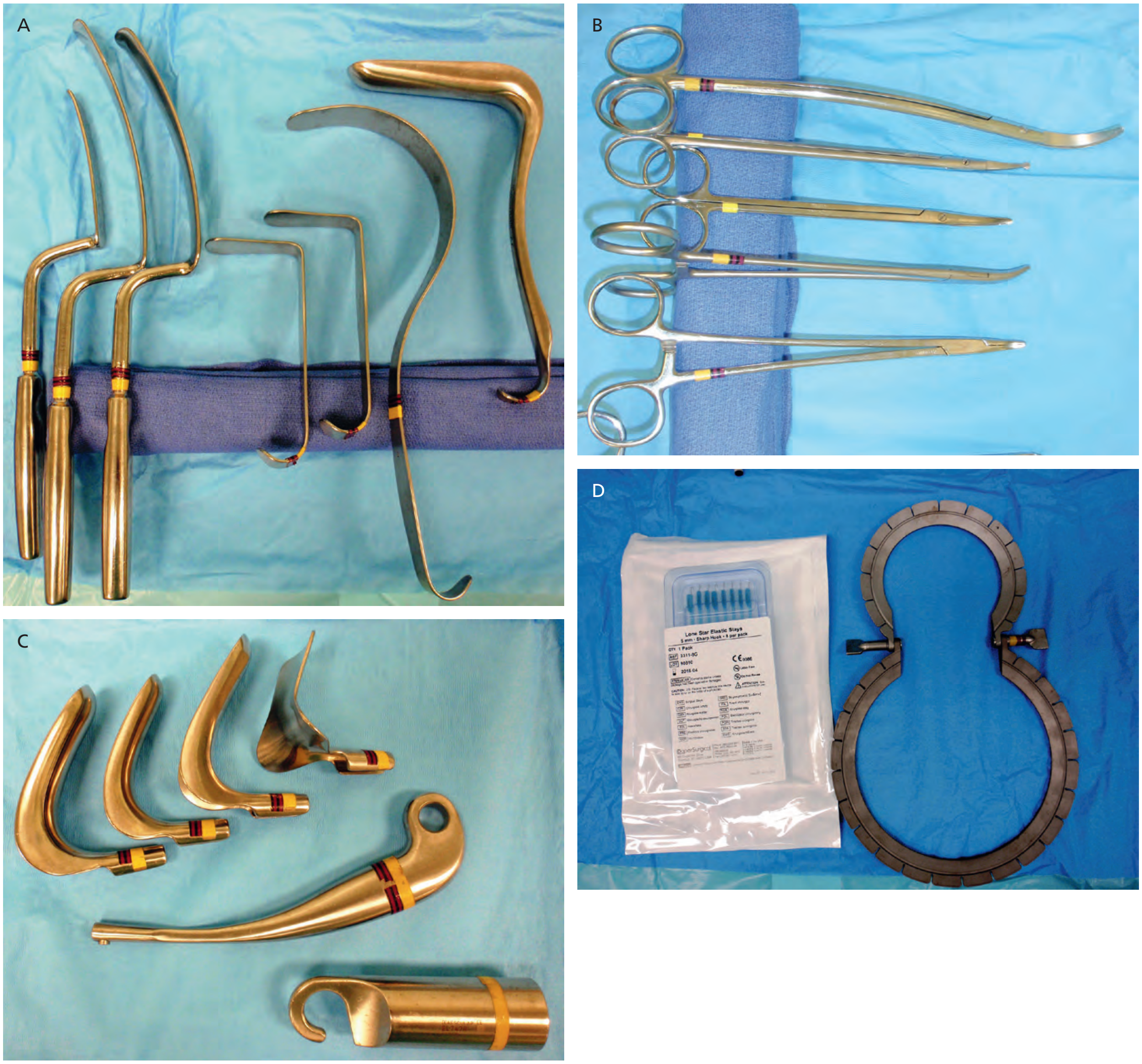

Figure 122.6 Vaginal surgery instruments. (A) (left to right) Breisky–Navratil vaginal retractors, Deaver retractors, Sim's speculum; (B) (top to bottom) S-shaped scissors, bubble tip scissors, Heaney curved needle holder; (C) weighted vaginal retractors; (D) Lone Star retractor.

Strulley's and Church scissors, two curved hemostats, one Lahey dissector, and one long Allis clamps and one Kelly clamp with a kittner. The surgeon will start out using a weighted vaginal retractor.

Supplies

These include a Lingeman-type GYN-Surgery Drape Pack, two 10-mL syringes, two suction tubings (one for regular suction and one for the drain bag on the drape), a 16F Foley catheter, drainage bag, marker pen and labels for medication, Steri-Drape to isolate the rectum, kittners to assist with dissecting, surgical stay hooks, vaginal packing, surgical knife blade (#15), needle protector, injection needle (21G × 1 inch) and TUR tubing set.

Set-up

This consists of an open prep tray on the prep table, an open major pack (table cover, five half sheets, two wet-proof drapes, 12 towels, one Mayo tray cover, two wet-proof towels, and four gowns) on the back table, and an open major basin set on a ring stand.

Circulating nurse

If some type of sling/mesh is to be used, the circulating nurse must ensure the implant is available *before* the patient comes into the OR. They should arrange for DVT prophylaxis (sequential compression device), and have appropriate antibiotics and lignocaine 2% (local infiltration) ready to place on the sterile field for irrigation when the scrub nurse is ready. All items used should be recorded in the room record, and all appropriate implant documentation filled out.

Scrub nurse

The scrub nurse sets up the back table in the usual manner. They may have to pass the instruments over the patient's leg and also may have to hold the Allis clamp for traction; therefore, the scrub nurse should ensure availability of several step-stools because the patients are generally in the lithotomy position with Yellofin stirrups, and some in the Trendelenburg.

Pharmacy

The following are required: antibiotic-impregnated vaginal packing (e.g. bacitracin, clindamycin, povidone–iodine), saline and water (3-L bag of saline for cystoscopy), antibiotics for irrigation (bacitracin 50 000 U in 1-L of saline), and bupivicaine 0.5% or 0.25% (with or without 1:200 000 epinephrine) to inject into the vaginal mucosa at the beginning of the case to help with dissection of the mucosa.

Universal protocol

The Joint Commission (JC) on Accreditation of Healthcare Organizations approved a Universal Protocol (UP) for preventing wrong site, wrong procedure, and wrong person surgery in July 2003, and it became effective on July 1, 2004 for all accredited hospitals, ambulatory care, and office-based surgery facilities [7]. The UP consists of three distinct sections: preprocedure verification, site marking, and a time out performed immediately prior to the procedure. The UP is applicable to any setting where invasive procedures are performed, not just the OR setting.

In accordance with the above regulation, before starting any intervention on the patient, all personnel in the OR use a "time out" to identify (1) correct patient, procedure, site, side, position, equipment, implants, images, medicines (labeled); (2) allergies and antibiotics; and (3) whether all labels from the previous case have been removed from the OR.

The World Health Organization (WHO) has realized the importance of the UP, and following its success in the USA, in 2005 it designated the JC and JC International (JCI) as the WHO Collaborating Center for Patient Study Solutions. Medical institutes must adhere to the UP to be considered as following "patient safety goals" and before acquiring JCI accreditation; 39 countries have already enrolled in the program.

Hazards

Laser

Laser technology has seen a booming market in urology. Innumerable lasers have been explored for various indications, e.g. resection/ablation of prostatic tissue, fragmentation of urinary tract stones, and ablation/incision of urinary tract stricture. The two most common lasers used in the USA are the holmium::YAG and Green Light™ lasers.

The laser produces an intense, highly directional beam of light. If directed, reflected, or focused upon an object, laser light will be partially absorbed, raising the temperature of the surface and/or the interior of the object, and potentially causing an alteration or deformation of the material. With increasing use of lasers in urology, it becomes imperative to be fully aware of their potential hazards and the safety standards necessary to prevent/treat these. There is scope in this chapter to describe important aspects only of laser safety and hazards. The reader can refer to http://www.laserinstitute.org/ for a comprehensive understanding of lasers.

Laser light can potentially damage eyes and skin. The effect varies with the frequency and intensity of the laser light. For example, KTP laser light, which is in the visible wavelength range (532 nm) causes retinal burns; whereas, holmium laser light, in the infrared range, damages more anterior parts of the eye, causing aqueous flare, cataract, and corneal damage. Although, skin is more protected from damage by laser, owing to the layer of dead cells and different absorption properties, healthcare lasers can cause burns, photosensitivity, and darkening. Laser also poses other hazards like electrocution, fire, and asphyxiation.

Therefore, all personnel in the OR must be aware of laser safety and comply with the mandatory safety regulations, both for their own safety and that of others. Undoubtedly, the most important part of the personal protective equipment (PPE) with regards to laser is the protective eyewear. It must be realized that the eyewear is wavelength specific; therefore, glasses that are protective for the Green Light laser are not suitable for the holmium laser, and *vice versa*. All personnel must wear appropriate eye-wear at all times until laser is no longer in use. The patient's eyes and eyelids should be protected from the laser beam in a method deemed appropriate by the laser safety officer. Any change in the status of the laser is must always be announced (e.g. active or standby). It must be remembered that there is no first-aid for laser exposure to the eye; therefore, prevention is the key. Appropriate warning signs, which preferably should include alarm lights, must be switched on outside all doors to the OR prior to the procedure. Any unwanted exposure to laser must be notified to the local authorities.

Realizing the high hazard potential of laser equipment, various governing bodies have drawn up mandatory regulations on safety standards for laser equipment as well as on safe practice by the user. In the USA, the Occupational Safety and Health Administration (OSHA) works to ensure safe working conditions for by setting and enforcing standards and by providing training, outreach, education, and assistance. It also governs laser administration. Complete documentation on laser use in healthcare is available in ANSI Z136.3-1996/2005 of the American National Standards Institute and all laser manufacturers must comply with these standards. The European equivalent standards are EN207/208/60825.

Radiation

Interventional fluoroscopy is an essential part of endourology; with advances in this field leading to more and more complex endourologic procedures, the exposure of the surgeon, staff and patients to fluoroscopy is increasing in parallel. The hazards of radiation to the patient include immediate or delayed skin injury and a small but real delayed risk of cancer. Studies from percutaneous transluminal coronary angioplasty have estimated long-term cancer risk to be 0.1% in men aged 60 years or older with exposure of 80 Gy/cm^2 (effective dose 20 mSv) [8]; the risk is estimated to be up to fourfold in children younger than 10 years [9]. The exposure of the surgeon during endourologic procedures is significantly less, yet still significant [10]. It is therefore important to be aware of the hazards of fluoroscopy and means of protection.

The recommendation for containment of radiation within the OR is a 2-mm equivalent of lead thickness in walls (a 15-cm thick concrete wall or a 25-cm brick/cement wall have equivalent radio-opacity) [6]. Adequate PPE, i.e. articulated shielding, lead aprons, gloves, thyroid shields, and glasses, must be available and must always be used. The minimum recommendation for lead garments is 0.25-mm lead thickness (optimum 0.35 mm) for protection against scattered radiation, and 0.50-mm lead thickness for protection against useful radiation. Two-piece lead aprons are ergonomically superior to single-piece ones in terms of back strain. There should be a visual indicator outside the OR whenever fluoroscopy is in use. All staff must be provided with dosimeters for periodic monitoring of radiation dose. The principles of proper shielding, minimizing time and radiation, and maintaining proper distance from the source are acronymed as ALARA (as low as reasonably achievable). The National Cancer Society has published guidelines for minimizing unnecessary radiation to patient and staff [11]. Documents on various concepts and recommendations on safe use of fluoroscopy are readily available from the International Atomic Energy Agency website [12].

Patient handouts

Patients undergoing any surgical procedure require both medical and nursing expertise. Preoperative teaching begins at the time of diagnosis. A short lesson that makes use of diagrams or models will help patients understand the anatomy of the organ system to be operated upon and assist in educated mutual decision-making. At the time of the initial consultation, the appropriate procedure is explained to the patient and any questions and concerns are addressed. Most often patients want to know the length of the procedure and hospitalization, the amount of pain and its treatment, and how long the recuperation period will be.

Prior to admission, a preoperative work-up is performed that includes a complete blood count, electrolyte measurements, urinalysis, and urine culture. If the urine culture is positive, the patient is treated preoperatively with antibiotics. Prothrombin time and partial thromboplastin time are determined if there is any history of bruising or bleeding. An electrocardiogram (ECG) and chest X-ray are performed depending on the patient's age and medical history. On admission to hospital, the patient's radiographs are reviewed again and informed consent is obtained.

As much as for the treating surgeon, it is important for the patient to understand their medical condition, available treatment options (with pros and cons), and, after decision on surgical option, the benefits/risks of the procedure, surgical details, approach, instructions in the perioperative period, and restrictions/precautions until complete healing or in the long term. Needless to say, to assimilate such a plethora of information, more than one session with the clinical team is required. In a busy practice, even the treatment counselor may find it difficult to discuss each and every aspect of treatment in details. Moreover, the patient is unlikely to remember everything even after thorough counseling.

To overcome the shortcomings of verbal counseling, handouts are patient-friendly tools that provide instructions and information in black-and-white, and are always available for ready referral. These also help the patient to generate questions for a more effective counseling session. Often the handouts also include useful information like location maps, addresses, and contact numbers. Patient handouts should be written in simple and common language. The components that should be included are given in Table 122.1 and an example handout for an artificial urinary sphincter in Table 122.2.

Acknowledgements

We acknowledge Mr Anurup Majumdar, Karl Storz® India, New Delhi, India for his help with the sections on OR set-up.

Table 122.1 Items in a patient handout.

1. Introduction to the normal anatomy and function (brief with figure)
2. Description of the disease (preferably with figure)
3. Description of the proposed procedure (e.g. benefits, side effects, anesthesia, incision – location and length, duration, requirement of prosthetics, grafts, blood products, dressings and tubings; preferably with figure)
4. Preoperative preparation for the procedure:
   - Any dietary change (e.g. clear liquids, with examples)
   - Any bowel preparation (e.g. enema, golytely, laxative tablets, with description)
   - Any part preparation (e.g. vaginal douching, pessary, hair clipping/epilation, bathing with antimicrobial soap)
   - Any medication ingestion (e.g. antibiotics, sedatives, antacids, with clear mention of dosage and schedule)
5. Location of surgery center (with map) – time to report, helpline number, location of attached vehicle parking
6. Postoperative instructions:
   - Attention to degree of discomfort (mention of pain, discharge, dressings and tubings, along with expected time of recovery)
   - Instructions of care of wound (e.g. change of dressings, removal of catheter/other tubings, personal hygiene); description of each procedure clearly and separately
   - Avoidance of certain activities along with duration of avoidance (e.g. straining, sexual activity); preferably mention the benefits
   - When, where and whom to follow-up with (along with address with map of location)
7. Information on emergency symptoms and signs:
   - Description of common/serious symptoms and signs (e.g. fever, pain in wound, discharge from wound, wound dehiscence, blockage of tubings)
   - Emergency contact numbers, emergency location (along with map)

Table 122.2 Patient handout for an artificial urinary sphincter.

Description

Anesthesia

You will have general/spinal anesthesia before the procedure. The aim of anesthesia is to keep you free of pain during the procedure. You will be unconscious during the general anesthesia and numb (from waist down) during the spinal anesthesia. You may feel somewhat uncomfortable during induction of anesthesia.

Prosthetic device

This device is planned for your leakage/continuous dribbling of urine during activities which increase your belly pressure (e.g. walking, coughing, sneezing, laughing, lifting, or exercising). For your degree of leakage, alternative modalities, i.e. sling and injections in the urethra, may not work as well. You should discuss with your doctor in detail.

An artificial sphincter has three parts:

- Cuff: fits around your urinary passage (named "bulbar urethra");
- Balloon/bulb: placed under your lower belly muscles to one side;
- Pump: placed in the scrotum (for men).

The cuff is always in the inflated state to keep your urethra in the closed state (to prevent urinary leakage). At the time of voiding, you will press the pump a few times to empty the cuff water back into the balloon; it will fill up again automatically in 1½ min.

You will have two small cuts, one each in the following locations to fit the device into place:

- Lower belly: for balloon and pump;
- Perineum: for cuff.

Please note, the device will *not* be active for 4–6 weeks immediately after the procedure for optimum healing. This means you *will* remain incontinent during this period and will have to use pads as you are using now.

Adverse effects and risks

This procedure is generally safe; however, any intervention may be associated with some risks and adverse effects (e.g. infection in the cut, opening up of the cut, clotting of blood in the legs, breathing problems/pneumonia, bleeding, etc.).

Risks for this surgery:

- Injury to the urethra or other adjacent organs (which may need an additional procedure and/or postponement of insertion of the device);
- It may become difficult to empty your bladder after the procedure (which may need catheterization);
- Urine leakage may not disappear completely;
- Malfunction/infection in the device (which may necessitate removal of the device).

Instructions prior to the procedure

Always tell your caretaker doctor/nurse what medications (prescription/over the counter) you are taking. Always tell them what other medical conditions or allergies you are suffering from. Any such information may be important for the clinician, e.g. medicines like blood thinners (Aspirin, clopidogrel, warfarin) need to be stopped a few days before the procedure; some medicines are permissible/desirable to continue through the procedure.

Your doctor will test your urine to make sure you do not have a urinary infection before starting your surgery.

On the day of your surgery:

- You will usually be asked not to drink or eat anything for 6–12 h before the surgery;
- Take the medicines your doctor told you to take with a small sip of water;
- Your doctor or nurse will tell you when to arrive at the hospital.

After the procedure

You may return from surgery with a tube in place in your urethra for draining urine from your bladder for a little while. It most likely will be removed before you leave the hospital. Your expected stay in the hospital will be less than 24 h. Please note that the final decision of length of stay will be decided by the clinicians in your best interest; they may want to watch you for a longer period – for your benefit.

About 6 weeks after surgery, you will be taught how to use your device; until then you will remain incontinent. You will need to carry a wallet card or wear medical identification that tells healthcare providers you have an artificial sphincter. The artificial sphincter must be turned off if you need to have a urinary catheter placed.

Outlook (prognosis)

Most people have significant benefit in terms of incontinence and improvement in quality of life after this procedure. You may become completely dry of urine and at least much less wet than before. Very few people may not benefit from the procedure at all. Generally, the benefit of the device remains for some 8–10 years and tends to wear away with time. This happens because of slow thinning (atrophy) of the urethra where it is inserted due to constant pressure; in such event, a new cuff needs to be surgically placed in a healthier part of the urethra.

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CHAPTER 123

Local Anesthesia for Minimally Invasive Treatment of the Prostate in the Office Setting

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Introduction

Despite a wealth of information regarding outcomes for most minimally invasive treatment (MIT) options for lower urinary tract symptoms caused by benign prostatic hyperplasia (BPH), there are a dearth of studies regarding the best method of local anesthesia for prostate procedures. No “standard” exists with respect to the office-based anesthetic protocol.

During the past decade, as minimally invasive techniques have proliferated, reimbursements for hospital-based procedures have diminished, while reimbursements for office-based procedures have increased. Physicians in private practice have increasingly sought to perform procedures in the office. Microwave procedures could be performed without intravenous analgesia [1]. Urologists also found transurethral needle ablation using radiofrequency energy and interstitial laser coagulation could be performed with local anesthesia in the office [2–4]. Currently, urologists are performing and developing techniques for safe and comfortable laser ablation of the prostate in the office setting. Such a trend may change as reimbursement changes; nevertheless, an in-office procedure has a potential to be safer (in that only local anesthesia is used), more convenient and efficient for the patient. Such procedures are also less costly overall, saving on hospital/surgery center fees and professional anesthesia charges. Whether urologists continue to develop and advance in-office MIT remains to be seen. Urologic outcomes should be similar to procedures performed in the hospital or surgery center with full anesthesia or intravenous sedation. True evidence-based conclusions comparing procedures performed with anesthesia and anesthetic monitoring to those performed under local anesthesia in the office do not exist.

This chapter will discuss the common pharmacologic agents that can be used as local anesthetics, and the application and techniques used to deliver local anesthesia. The techniques used to anesthetize the prostate for MIT are in evolution. It is hoped that the information presented will stimulate proper study for the development of improved local anesthetic protocols and techniques. Any local anesthetic protocol for the performance of MIT of the prostate in the office setting should have the following goals: (1) to provide satisfactory anesthesia such that the patient and surgeon feel comfortable with the performance of the procedure in the office setting; (2) to safely administer the anesthetic so that proper patient monitoring requires nothing more than vital signs and observation; (3) to minimize the risk of complications or bleeding that might interfere with proper performance of the procedure; (4) to carry out the MIT in a fashion that is complete and not compromised by the fact that local anesthesia is used instead of regional (i.e. spinal) or general anesthesia.

Patient selection and preparation

In order to enhance the likelihood of patient acceptance and comfort, preoperative counseling is paramount. The experienced urologist should also develop the skill of

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patient selection, much like that in selecting patients for in-office vasectomy and cystoscopy. Patient size, prostate size, and patient comfort level with the office physical examination and preoperative counseling need to be taken into account. Patients should be counseled on the likelihood that they will not be fully anesthetized such that they will not be numb to all feeling. Some discomfort should be expected but this should be mild and generally well tolerated. Time should be spent explaining the delivery technique of the local anesthetic so that patients know what to expect.

Pelvic neuroanatomy

The following is a brief discussion of the relevant prostatic and urethral neuroanatomy. With a basic knowledge of genitourinary innervation, it is easier to understand which nerves can be appropriately targeted for prostatic and posterior urethral anesthesia.

The inferior hypogastric (pelvic) plexus receives both sympathetic (hypogastric nerve) and parasympathetic (pelvic splanchnic nerve) innervation. The plexus is a 4–5-cm long rectangle and its midpoint reaches to the tip of the seminal vesicles [5]. It runs on either side of the rectum, communicating behind the rectum and sending branches to encompass the vesical neck (Figure 123.1). The distal end of the pelvic plexus gives off branches to the posterior lateral aspect of the prostate, running in close association to the arterial and venous supply (neurovascular bundle) [6]. The nerves lie in the lateral endopelvic fascia near its junction with Denonvilliers' fascia [7]. The nerves then coalesce at the apex of the prostate at the 5 and 7 o'clock positions [8, 9]. Superficial branches innervate the urethral sphincter at the 3 and 9 o'clock positions, while deep branches are sent to the bulbourethral glands. As the cavernous nerves reach the penis, branches innervate the urethra at the 1 and 11 o'clock positions, while small branching fibers join the dorsal nerves of the penis [4, 5].

The pudendal nerve originates from Onuf's nucleus in the sacral spinal cord (S2–S4), leaves the pelvis between the piriformis and coccygeus muscles, and enters the greater sciatic foramen [10]. It then re-enters the pelvis through the lesser sciatic foramen and passes through the pudendal canal. Branches are sent off to the rectum (inferior rectal nerves), perineum (perineal nerve), and penis (dorsal nerve of the penis) [11]. The urethral sphincter has both autonomic and somatic innervations. Hollabaugh *et al*. performed a study of 12 fresh cadaveric dissections and confirmed the presence of an autonomic (pelvic nerve) and dual somatic (intrapelvic pudendal and perineal nerve) innervations of the rhabdosphincter [12].

From these descriptions it can be reasoned that a local anesthetic delivered anywhere from the seminal vesicles to the apex of the prostate should have some effect on sensory input from the prostate. Likewise, the rhabdosphincter could also be affected by nearby local anesthetics.

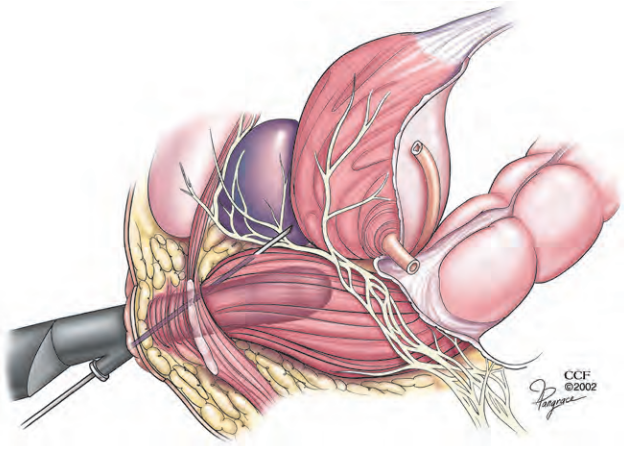

Figure 123.1 Prostatic neuroanatomy. The inferior hypogastric (pelvic) plexus lies on either side of the rectum and its midpoint stretches to the tip of the seminal vesicles (reproduced with permission from Dr Stephen Jones and the Cleveland Clinic Foundation).

Local anesthetic pharmacology

Local anesthetics act by inhibiting voltage-gated sodium channels that allow sodium ion influx into the nerve. This results in membrane stabilization and inhibition of neuronal action potential [13]. Amide local anesthetics are the most common class of anesthetics used by urologists. Allergic reactions are class specific, meaning that a person may have a hypersensitivity to multiple anesthetics in the same class [13].

The addition of epinephrine (1:200 000) can provide vasoconstriction. This will decrease blood flow to the injected area, decrease intraoperative bleeding [14], and causes a slower reabsorption/extended effect. Epinephrine should not be injected into areas that are supplied by end-arteries (fingers/toes, glans penis, nose, etc.).

Amides are common local anesthetics used in urology and include lidocaine, bupivacaine and mepivacaine (Table 123.1). Lidocaine is the most commonly used local anesthetic and it is well known to urologists. It can be given as a 0.5% or 1% solution at a maximum dose of 3–5 mg/kg. The onset of action is 2–5 min and it has duration of action of 30 min to 2 h [15]. A 0.5% solution provides 5 mg/mL, so an 80-kg person can receive up to 80 mL of a 0.5% lidocaine solution or 40 mL of a 1.0% solution.

Bupivacaine has more than twice the duration of action of lidocaine. A full dose of bupivacaine is

Table 123.1 Common local anesthetics used in urology (from Berde and Strichartz [13], with permission).

	Concentration (%)	Dose (mg/kg)	Onset (min)	Duration (h)
Lidocaine	0.5–1.0	3–5	2–5	0.5–1
Mepivacaine	0.5–1.0	4	3–5	1–1.5
Bupivacaine	0.25–0.5	1–2	2–10	2–4

Table 123.2 Oral medications for minimally invasive prostate therapy [15, 47].

	Dose (mg)	Onset (min)	Duration (h)	Toxicities
Benzodiazepines				
Diazepam	5–10	45–90	2–4	Respiratory, seizures, anaphylaxis
Lorazepam	1–2	45–90	6–12	Respiratory, seizures, anaphylaxis
Alprazolam	0.25–0.5	60	6	Respiratory, seizures, anaphylaxis
NSAIDs				
Naproxen	220	30–60	7–12	Gastrointestinal, bleeding, renal
Ketorolac	10	30–60	4–6	Gastrointestinal, bleeding, renal
Narcotics				
Hydrocodone/acetaminophen	1–2 tabs (5/500)	10–30	4–6	Respiratory, constipation
Oxycodone/acetaminophen	1–2 tabs (5/325)	10–30	4–6	Respiratory, constipation
Anticholinergics				
Hyoscyamine	0.125	2–3	4	Gastrointestinal, urinary retention, dry mouth

1–2 mg/kg, or 3 mg/kg in combination with epinephrine. A 0.25% solution provides 2.5 mg/mL of bupivacaine, so an 80-kg person can receive up to 64 mL of a 0.25% solution or up to 32 mL of a 0.5% solution. There is a known toxicity of ventricular arrhythmias/cardiac arrest with overdosing [15].

Mepivacaine is dosed at up to 4 mg/kg with a quick onset of action of 3–5 min and a duration of action of 45 min to 1.5 h. A 0.5% solution provides 5 mg/mL of mepivacaine, so an 80-kg person can receive up to 64 mL of a 0.5% solution or up to 32 mL of a 1.0% solution. Toxicities include central nervous system (CNS) side effects/seizures and bradycardia/heart block [15].

In general, toxicities can occur if an overdose of anesthetic is given, or if the anesthetic is mistakenly injected into the vasculature. Proper infiltrative techniques, including a fundamental knowledge of the surrounding anatomy and aspiration prior to injection of the anesthetic, help to avoid these complications. CNS side effects include a spectrum of symptoms from tinnitus and metallic taste in the mouth to seizure activity. Cardiovascular side effects range from bradycardia, atrioventicular block, and ventricular arrhythmias to cardiac arrest [15]. Allergic reactions can occur at any dose if there is a hypersensitivity, and can cause anything from hives to overt anaphylactic shock. Amide anesthetics are metabolized by the liver and excreted by the kidneys, so the dosage should be decreased in patients with either liver or kidney failure [13]. For the purpose of local anesthetic for MIT of the prostate, the doses needed for a reasonable block seem to be well below anything close to the maximum dose, making toxicities very unusual. Lidocaine is clearly the most commonly used agent in the office setting.

Oral supplementation

Virtually all office-based MIT protocols for the prostate involve preoperative oral medications to mitigate pain, anxiety, and bladder symptoms. As such, oral pain medicines, sedatives, and antianxiety medications are often considered along with anticholinergics. These preoperative "cocktails" are developed by word of mouth, with urologists sharing experiences as they bring a MIT into the office. The use of oral medications, while likely very beneficial to patients, has not been studied in a way that allows "best practices" to be established. It can be safely said that the preoperative medications used are generally very well understood by urologists, who use similar medicines in the day-to-day management of their patients (Table 123.2). Any study of local anesthesia for MIT of the prostate will be hampered by the added effects of these oral medications. If a local anesthetic technique is capable of working alone for a specific MIT, it must be proven as effective without oral supplemental agents. Nevertheless, preoperative oral medications that add to patient comfort and safety are clearly appropriate.

Topical urethral anesthesia

Prior to flexible cystoscopy being available, urologists routinely performed rigid diagnostic cystoscopy in the office with or without an anesthetic gel, such as 2% lidocaine. There is no question that a significant number of patients found the exam very uncomfortable and rarely would any patient suggest there was no discomfort at all. Urologists experienced with rigid cystoscopy understood that most of the discomfort tended to occur as the scope traversed the membranous and prostatic urethra, straightening the bulbous and proximal urethral anatomy. Patients reflexively resist cystoscopy by tightening the perineal musculature and membranous urethra. However, once in the bladder, patients would often relax with the words “the worst part is over”. The diagnostic cystoscopy could then be completed in most instances. Again, patient selection was still very important in enhancing the odds of a successful procedure.

Though lidocaine gel has been used for decades for cystoscopy in males, the proof that it works well as a local anesthetic is lacking. Stein *et al.* showed no benefit of lidocaine gel compared to a water-based lubricant for rigid cystoscopy in males in a prospective randomized controlled double-blind study [16]. Dwell time for the lidocaine was 5–10 min. In an effort to see if dwell time was insufficient, Goldfischer *et al.* performed a similar study using 30 mL of 2% lidocaine gel with a dwell time of 20 min before cystoscopy, comparing this to water-soluble lubricant. They found a slightly significant difference in patient perceived pain scores [17]. Both lidocaine gel and lubricant-only groups had discomfort and perhaps the difference was not clinically significant, as urologists could not differentiate who received lidocaine and who did not. There are numerous modern studies suggesting that 2% lidocaine works no better than water-soluble lubricant for flexible cystoscopy in the male [18–22].

It is therefore of interest that virtually every publication of in-office MIT of the prostate discusses some form of topical lidocaine instillation transurethrally. It is likely that very little lidocaine is actually delivered to the prostatic urethra or is able to dwell there. Normal retrograde urethrograms seldom show much contrast in the prostatic urethra. Some urologists add cooled 2% lidocaine solution instilled through a catheter to their MIT protocols. Though intravesical lidocaine has been used as a local anesthetic for bladder procedures, it has not been suggested as a prostatic anesthetic [23, 24]. Until studies are done comparing procedures performed with topical lidocaine to those performed without, the true value of topical lidocaine is open for discussion in MIT protocols. That said, all catheter-based technologies [i.e. transurethral microwave thermotherapy of the prostate (TUMT)] call for some form of lidocaine gel instillation before placing the catheter. Likewise, most technologies for MIT involving endoscopes call for lidocaine topical gel as an added local anesthetic. In general, 10–30 mL of 2% lidocaine gel is instilled for a 5–20 min dwell time prior to the particular procedure. Cooling the gel may aid in the comfort of delivery [25]. There should rarely be any complication from transurethral lidocaine gel and system levels of lidocaine are not seen [26]. If indeed lidocaine gel is nothing more than a placebo, it may be a valuable placebo. Both patients and urologists are comforted by the idea of delivering an anesthetic through a “painless gel” rather than a needle, which is what is required for any of the prostate blocks that are discussed below. The current evidence, however, suggests topical local anesthesia to the urethra and prostate for MIT procedures probably is marginal in its true value, and clearly more expensive than water-soluble lubricant.

Prostate blocks

MIT options for the prostate that involve high-powered TUMT or rigid cystoscopy with either transurethral needle ablation, interstitial laser energy or laser evaporative/ablative techniques require more than simple topical lidocaine to the urethra. These endoscopic procedures must be performed with clear visualization of the prostatic urethra for optimal performance. Any sudden motion of the patient can jeopardize the procedure because of bleeding or patient discomfort. As such, all procedures were originally developed under general, regional (spinal) or intravenous sedation.

Urologists experienced with prostate blocks for prostate biopsy and transurethral needle injection technique began to develop techniques to block the posterior urethra and prostate in such a way that these procedures could be performed in the office setting. They were motivated to develop their own in-office protocols in the hope of saving overall costs without diminishing physician reimbursement. Standard techniques developed after evidence-based studies have not been established. Local anesthesia involving prostate blocks for MIT are still evolving. There are no studies comparing different in-office local anesthetic techniques for MIT. There are, however, articles on local prostate block for prostate procedures and much has been written on local anesthesia for prostate biopsy.

Moffat injected 10 mL of 1% lidocaine with epinephrine into each lobe of the prostate of 18 patients via a digitally-guided transperineal route using a 20G spinal needle [27]. Then, using nothing more than topical lidocaine per urethra, he was able to dilate the urethra to 30F using sounds, and he then performed transurethral resection of the prostate (TURP) using a 28F resectoscope sheath. All procedures were performed in the operating room with anesthesia monitoring. Supplemental sedation was required in 10 of 18 patients. Remarkably, eight of the 18 patients had no intravenous sedation and no preoperative medications were given. Though this technique was seldom used, the fact remained that injection of lidocaine directly into the prostatic parenchyma must have anesthetic value if it allowed for a full TURP. Orandi followed up on this in 1984, describing multiple endoscopic procedures, including TURP, performed using transurethral lidocaine injected into the prostate and bladder neck via a specially devised endoscopic needle [28]. Supplemental oral and parenteral medications were used in his cases. The publication was presented as a "cost reducing idea." The technique similarly did not catch on. In 1993, Hugosson *et al.* published their results with transurethral incision of the prostate under local anesthesia [29]. Mepivacaine was injected transurethrally under direct vision into the bladder neck and posterior prostate to allow performance of a 6 o'clock incision of the prostate to treat men with lower urinary tract symptoms. The patients apparently received no supplemental preoperative or intraoperative medications. Twenty-eight of 30 patients claimed they would agree to the same procedure if another were needed. These examples suggest that local prostate block can allow for major endoscopic prostate procedures and that the block itself is responsible for pain control as opposed to oral or parenteral supplements.

Prostate blocks did not become common place, however, until the development of transrectal ultrasound-guided biopsy and ultrasound-guided periprostatic and intraprostatic blocks. Prior to transrectal prostate ultrasound, digitally-guided transrectal biopsy of the prostate was routinely performed with acceptable patient tolerance using no anesthetic. As template biopsies were developed in the prostate-specific antigen (PSA) era, along with saturation biopsy, local anesthetic techniques developed and showed that transrectal ultrasound-guided lidocaine for periprostatic block at the prostatic base could mitigate the discomfort of the biopsy [30–32]. Subsequent studies suggested that ultrasound-guided transrectal lidocaine at the apex worked just as well or better [33–36]. Transrectal intraprostatic injection of the prostate has been suggested as better than a periprostatic block for pain control [37]. Finally, a periprostatic and intraprostatic combination block may work best of all for transrectal ultrasound-guided biopsies [38, 39].

Armed with the knowledge that prostatic block could work in the operating room for transurethral resection procedures and that transrectal block worked well for prostate biopsies, urologists are adapting these technologies for office-based MIT of the prostate. The optimal technique is not yet known for any of the MIT modalities available today. As TURP took more than three decades to be considered a "gold standard," likewise it will likely take years before the new "gold standard" is born for MIT for male lower urinary tract symptoms due to BPH that can be performed in the office under local anesthesia.

Transrectal block for office-based minimally invasive treatment

Though most urologists are aware of and familiar with transrectal ultrasound-guided periprostatic and intraprostatic blocks for prostate biopsy, it should not be assumed that this will be optimal for transurethral MIT of the prostate. The incidence of febrile episodes after transrectal prostate biopsy may be increasing. Nam *et al.* found hospital admission rates after transrectal ultrasound-guided biopsy of the prostate increased fourfold from 1996 to 2005; 72% of these were admissions for infection [40]. Efforts should be made to ensure the rectal vault is empty of stool prior to biopsy and prophylactic antibiotics should be given.

The standard technique calls for ultrasound-guided injection of at least 5 mL of 1% lidocaine into the fat plane seen laterally at the base of the prostate, between the seminal vesical and rectum. On sagittal view, this appears as a "triangle," referred to by Jones as the "Mount Everest sign" (see Video 123.1) [30]. Each side must be injected. Alternatively, or at the same time, 5 mL of 1% lidocaine can be injected into the periapical fat, deep and lateral to the apex, between the prostate and rectum. On sagittal view, infiltration of anesthetic can be seen to separate a tissue plane that courses towards the base [33, 36]. The article by Berland and Jones in e-medicine fully describes transrectal periprostatic blocks and is a useful website. Using the same ultrasound-guided technique, intraprostatic anesthesia can be delivered by injecting 10 mL of lidocaine in increments in two to three sites within each lobe of the prostate from apex to base [37]. Though none of the transrectal local lidocaine blocks was developed for procedures other than biopsy, urologists have adapted them for MIT.

Kedia used a digitally-guided transrectal lidocaine block to perform interstitial laser coagulation of the prostate [41]. Other than transurethral lidocaine (a liquid and gel), patients received no oral or parenteral medications other than antibiotics. Turk has performed Evolve™ laser transurethral resection procedures in the office without any intravenous sedation, assisted in part by transrectal ultrasound-guided periprostatic block

[42]. However, it should be noted that he now favors a transurethral prostatic block. Meyer has performed many Prostiva™ radiofrequency procedures in the office using a transrectal periprostatic block with lidocaine from apex to base on each side, although oral analgesics and sedatives are used. He claims not to have terminated or abbreviated any procedures in over 300 cases (personal communication). Even TUMT procedures are being done with a transrectal block; transrectal ultrasound (which is needed to position the treatment catheter) is used to guide the lidocaine for a prostate block prior to the placement of the treatment catheter. Many TUMT procedures can be performed without a formal prostatic block. Members of our group are performing laser (Evolve and Green Light) procedures using transrectal ultrasound guided periprostatic and intraprostatic blocks with lidocaine. Good functional outcomes were recently presented at our State Urological Society Meeting [43].

Transperineal block

The transperineal block, though likely least utilized today to provide local anesthesia to the prostate, has the potential for resurgence if in-office MIT procedures continue to develop. Unlike the transrectal technique, the risk of infection should be lessened by allowing for a proper skin preparation and directing the needle to avoid contamination from the rectal mucosa.

A modern technique has been nicely described by Issa *et al.* [3] and Cohen and Steiner [44]. The patient is placed in the dorsolithotomy position with the perineum prepped and draped. A 27G needle may be used to anesthetize the entry site in the perineum above the perineal body. A 22G spinal needle (3.5 inches long) is attached to a 20-mL Luer Lock syringe containing the anesthetic (i.e. 1% lidocaine). The needle is directed into the midline, deep to the apex of the prostate under transrectal digital guidance. The anesthetic solution is infiltrated, defining a plane between rectum and prostate that may be palpated as the rectum is elevated from the prostate. At least 10 mL of the anesthetic solution is injected deep to the prostate on the right and then the left, from apex to base. This should deliver anesthetic levels similar to transrectal anesthetic technique. The needle need not be removed from its insertion site as injections occur, as aspirating periodically ensures that the injection is not into venous spaces. Interstitial laser coagulation (ILC) therapy has been successfully performed without the need for intravenous sedation using the transperineal periprostatic block [3].

A simple technique for transperineal digitally-guided block of the urethrosphincteric region has been recently described by Al-Hunayan *et al.* [45]. They injected 5–10 mL of lidocaine into the region just caudad to the apex of the prostate, above the rectum on each side of the midline. Their technique showed improved comfort with rigid cystoscopy over lidocaine per urethra (Figure 123.2). Likewise, transurethral needle ablation of the prostate has been similarly performed [46].

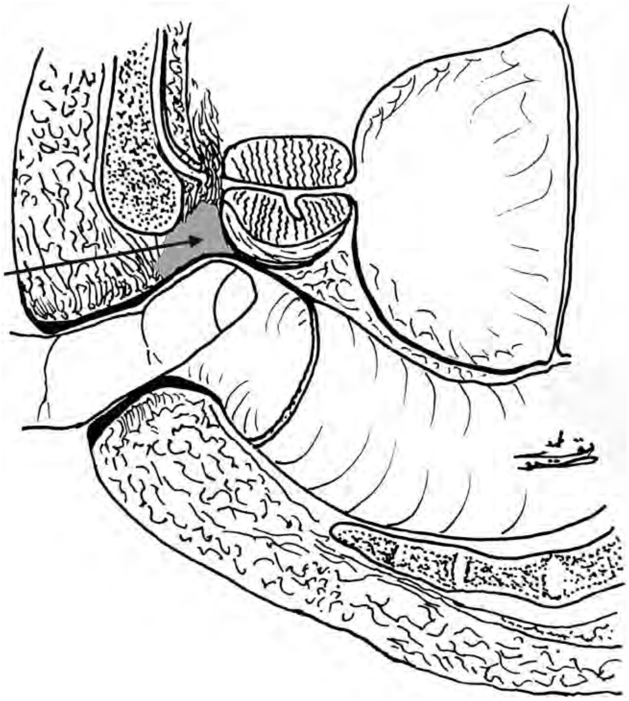

Figure 123.2 Digital guidance for transperineal prostatic block. This depicts the infiltration of lidocaine (gray area indicated by arrow) in a location bounded by the rectum posteriorly, the rhabdosphincter anteromedially, and the apex of the prostate superiorly (reproduced with permission of Dr Al-Hunayan and Springer Science Business Media [45]).

As mentioned earlier, TURP has been performed using a transperineal intraprostatic block without the need for intravenous sedation [27]. The transperineal route could also be very easily used to perform intraprostatic injection of anesthesia for MIT. Using an anesthetic agent that contains epinephrine could potentially mitigate bleeding for transurethral procedures. Though not studied specifically for MIT, this route also would have an added advantage over the transurethral intraprostatic injections in that the prostatic lumen could be avoided by targeting the needle laterally, thus minimizing potential bleeding from the needle entrance site in the prostatic urethral lumen. Clearly, if the procedure is planned in the office, the MIT modality itself should already be proven to minimize the risk of bleeding.

Transurethral prostate blocks

Since originally described by Orandi, transurethral prostate blocks have been reinvented by urologists in order to perform local MIT of the prostate in the office setting. The technique can easily be performed by any urologist using a flexible injection catheter passed via the cystoscope. The patient is prepared for rigid cystoscopy in the lithotomy position. Oral agents, both analgesics and sedatives, can be helpful. The cystoscope is passed and the prostatic lumen and bladder are examined. An injection catheter (Bard Contigen, Cook Urologic, Storz reusable, etc.) can then be used to inject 3–5 mL of an anesthetic solution (i.e. lidocaine) into the bladder neck at the 5 and 7 o'clock positions. The cystoscope is then moved distally to view the prostatic lobes which are then anesthetized by injecting at the 3 and 9 o'clock positions with additional lidocaine. Injections can be repeated in different areas if needed for longer or larger glands (see Video 123.2). Patient selection is important. The transurethral block also avoids the rectum and its potential for infection. Using this technique, urologists have performed interstitial laser coagulation, transurethral needle ablation, and laser prostatectomies, including Green Light and Evolve laser prostatectomies. TUMT time can be diminished by transurethral mepivacaine with epinephrine, with improved comfort [14]. These procedures have been performed in the office without the need for an intravenous line or special monitoring, other than close observation and periodic measurement of vital signs. Published studies regarding outcomes are lacking. Though members of our group have used this technique, they have found bleeding occasionally problematic for laser ablation procedures and now prefer the transrectal technique previously mentioned.

Pudendal nerve block

Pudendal nerve block is mentioned as it may have endourologic application for the lower urinary tract, and it is an anesthetic that can be delivered by the urologist. Mahmood Hai (Dearborn, MI, USA)probably has the world's greatest urological experience with pudendal nerve block in men, a technique he developed from his knowledge of pudendal blocks in women. In his surgery center he has performed outpatient photoselective vaporization of the prostate on over 1000 patients. His technique involves a transperineal approach. Two 20G 12-cm disposable spinal needles are attached to 20-mL syringes loaded with a 0.5% lidocaine solution. For right-handed urologists, the left index finger is inserted rectally to identify the landmarks; the ischial tuberosity, ischial spine, and sacral spinous ligaments. The needle is inserted perpendicular to the skin about 2.5 cm posteromedial to the ischial tuberosity. The needle is slowly advanced through the ischial rectal fossa towards the ischial spine, guided by the rectal finger. As the needle hits the spine, it is pushed posterior to it by the guiding finger. This places the bevel of the needle at the beginning of Alcock's canal. After attempted aspiration in two planes to make sure the needle is not in a blood vessel, 5 mL of the solution is injected. In most instances, the wheel produced can be palpated by the rectal finger. The needle is advanced about 0.5 cm and the remaining 5 mL are injected. The needle is withdrawn and firm pressure is applied over the area by the rectal finger for 1–2 min. A similar procedure is done on the opposite side (see Video 123.3). The anesthetic should be effective within 5 min and photoselective vaporization of the prostate can be started (see Video 123.3).

This form of anesthesia is not one that should be considered in the office setting without an intravenous line and proper monitoring. There is a potential for bleeding and nerve damage, as can rarely occur with any regional nerve block. Dr Hai does have an intravenous line for sedation, monitored by an anesthesiologist. Nevertheless, it is worthwhile being aware of this technique as it represents a locoregional anesthetic which urologists can and are being trained to perform. More study will be needed before we know the true risk-to-benefit ratio compared to other anesthetic techniques.

Conclusions

This may be a new era in urologic practice; treating more patients in the office with MIT of the prostate. As technologies evolve, so will the consensus of "best practice" regarding office-based local anesthesia. Studies are sorely lacking that compare one anesthetic technique to another. The potential for tremendous cost savings still exists if the hospital and anesthesiology charges can be avoided by office-based therapy. Office-based therapies, however, must be proven to be just as effective with comparable long-term result. Urologists interested in pursuing office-based procedures under local anesthesia should realize that the information presented in this chapter will hopefully be dated in 5 years, as more outcome and comparative studies are done so that evidence-based recommendations can be made on the "best practice" of office-based anesthesia for the MIT of the prostate. It is likely that combining the techniques described in this chapter will result in improved local anesthesia for MIT of the prostate. Finally, without question, new technologies and techniques will continue to arise to treat lower urinary tract symptoms due to BPH. Office-based therapy has a great potential to provide for major cost savings as long as the urologist finds it economically viable to pursue such care in the office. Regardless, all urologists should be aware of the importance of minimizing anesthetic risks and cost for MIT of the prostate. Local anesthetic techniques may diminish anesthesia needs, time of recovery, and costs.

These cost savings may also be realized in the hospital or ambulatory surgery center setting. Such techniques might be applicable to more invasive hospital-based procedures, such as TURP in high-risk individuals or the very elderly, where close anesthetic monitoring is always required. The anesthetic risks may possibly be diminished by the use of local anesthetics. Similarly, though MIT of the prostate may be easy to perform in the office, caution and proper monitoring are always needed in high-risk or very elderly patients. Judgment is always required in selecting candidates for office-based MIT of the prostate using local anesthesia.

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Useful website

http://emedicine.medscape.com/article/459599-overview

CHAPTER 124

Microwave Therapy

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Introduction

The application of heat for the management of numerous complaints and diseases is a well-known in medicine. However, it was not until the late 1980s that treatment of the prostate used microwaves and radiowaves to produce heat delivered either rectally or transurethrally [1]. Hyperthermia, defined as a temporary heating of the body or parts thereof to temperatures (>40–45°C) not resulting in denaturation of proteins, was the first technique to be developed. This has developed into thermotherapy, in which temperatures range from 45 to 60°C, resulting in effective necrosis [1]. Many different energy sources are used to produce heat, but application of microwave technology, solely through the transurethral route, has gained a firm position in currentl ablative methods due to the excellent clinical results obtained in the treatment of lower urinary tract symptoms (LUTS) due to benign prostatic hyperplasia (BPH).

Principles

Microwave thermotherapy of the prostate involves the emission of microwave radiation through an intarurethral antenna to deliver heat within the prostate, with the goal of destroying tissue by achieving temperatures that exceed the cytotoxic threshold. The extent of the necrosis is governed by two physical variables: intraprostatic temperature and duration of heat exposure [2]. If the intraprostatic temperatures do not get high enough, the treatment needs to be for longer, and *vice versa*.

Microwaves are electromagnetic radiation with an oscillating electrical and magnetic field in the range of 300–3000 MHz. Microwaves follow the basic physical properties of electromagnetic radiation transmission in free space or in a medium, and are reflected, deflected, or scattered at the interfaces of two media with different impedances. The heat is produced when the microwaves are absorbed by the tissue, and arises mainly by two processes: electric dipoles, e.g. water molecules, which oscillate in the field; and electric charge carriers, e.g. ions, which move back and forth in the field. These movements transfer energy to the tissue in the form of heat.

The penetration of microwaves is usually defined as the tissue depth at which the strength of the microwave field has decreased to 37% of its original value [3]. Penetration is deeper in low-water content tissue (fat) than in high-water content tissue (muscle, prostate), because the water molecule is a primary absorption target [4]. It also depends on the wave frequency: The higher the frequency, the shorter the wavelength and thus the smaller the penetration depth in the tissue. Ideally, the penetration in water-rich tissues is approximately 100 mm at 100 MHz, while at a frequency of 2450 MHz the penetration is reduced to approximately 10 mm. Another important physical principle of microwave-induced heat distribution is that it is distance dependent: the farther the target from the microwave applicator, the lower its temperature. This

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temperature decrease is due to the declining microwave penetration and cooling effect of blood flow. Based on this principle, it is obvious that the peak temperature will occur at the mucosa adjacent to the applicator. In order to move the peak of the heat distribution into the prostate and to avoid injury to adjacent tissue, a surface coolant was introduced to reduce the temperature in the vicinity of the applicator.

The transurethral microwave thermotherapy (TUMT) devices, used for the management of symptomatic BPH, consist of a power oscillator, urethral cooling system, temperature monitoring system, and control console. The energy is delivered to the target tissue by the microwave antenna through a transurethral catheter, while the treatment is controlled by a computer software system. The transrectal route was proved problematic and has been abandoned; it heated the periphery and not the transition zone of the prostate, appropriate and stable positioning of the probe was difficult, and long-term results were disappointing.

Experimental studies: mechanism of action

Microwave delivery systems designed to heat prostatic tissue were initially tested *in vivo* in a dog model [5, 6]. In addition, researchers evaluated the histopathologic alterations in the canine prostate after hyperthermia and thermotherapy [7, 8]. All these pioneering animal studies have provided the experimental basis for many of the principles applied in the treatment of humans and have shown the method to be feasible and safe. Studies on the human application of thermotherapy (temperature > 45°C) were started in the early 1990s by Devonec *et al*., who treated patients with symptomatic BPH during 50-min sessions, which gave mild relief [9].

The most recent experimental studies have focused on understanding the mechanism of microwave thermotherapy and the factors that can influence the treatment outcome, in order to eventually individualize the therapy and optimize the clinical result.

It has been shown that heating to in excess of 45°C results in coagulation necrosis [10], following the general pattern of burn wounds that is characterized by inflammatory reactions that lead to a rapidly developed necrosis and edema [11]. Microthrombi will occlude vessels and the blood flow will not be adequate for cell survival, and even less so for repair. At the cellular level, heat causes thermal inactivation of enzymes and structural proteins, and rupture of cell membranes. Cell death occurs when the thermal damage is so severe that repair mechanisms (replacement of enzyme proteins and synthesis of new membranes) are insufficient or when the DNA and RNA transcription enzymes that mediate the repair mechanisms are destroyed [12–14].

In one of the earliest studies, Moritz and Henriques showed that the thermal damage to pig skin exposed to 45°C for 7 h was approximately the same as that following exposure to 50°C for 5 min [15]. Cell survival studies on mammalian cells confirm the relationship in the temperature range used for microwave thermotherapy: 43–57°C [12]. However, different cell types and tissues may have different heat sensitivity, reflecting differences at the sub-cellular level: a change of only a few amino acids in proteins can make them more or less heat resistant [12]. A significant finding is that in order to maintain the same biologic isoeffect for a given cell line, the duration of heating should be increased by a factor of about 2 (R value) if the temperature is decreased by 1°C [12].

It was reported that apoptosis was observed in a variety of cell systems at temperatures lower than those inducing necrosis [16]. In the periphery where the thermal exposure is lower, apoptosis may be the contributing cell kill mechanism [11, 17]. Brehmer and Svensson investigated the feasibility of using heat to induce apoptosis in human prostatic stromal cells. Cell cultures were exposed to 47°C for 1 h and the most extensive apoptosis (in 76% of the cells) was noted 24 h after heat treatment [17].

It has also been proposed that induced necrosis disrupts periurethral alpha-adrenergic receptors, reflecting in denervation of the smooth muscle cells [18]. These findings may be responsible for the increased urinary flow after TUMT. It has been demonstrated that TUMT increases the sensory threshold (evoked by electrical stimulation) in the posterior urethra by 30% or greater, resulting in the alleviation of irritative symptoms [19].

Factors affecting thermotherapy of the prostate

Thermotherapy of the prostate is mainly affected by the three main steps that control the course of the treatment: (1) generation of microwave power, delivery of the energy to the tissue, and generation of heat through absorption of the applied microwave energy; (2) dispersion of heat by conduction in the tissue; and (3) loss of heat through blood flow.

Generation, delivery, and absorption of microwave energy

The first step depends on the operating characteristics of the TUMT device and the antenna used to deliver the energy. Several TUMT devices are available and differ in frequency of the generator and design of the antenna. While it is known that microwave penetration depends on the wave frequency, it has also been demonstrated that the prostate is heated in the vicinity of the antenna where the electromagnetic field is disturbed; thus the penetration depth of the microwave or heat is independent of the frequency within the broad interval from 680 to 2450 MHz [20]. Therefore, the range of coagulation necrosis achieved by a standard TUMT with an applicator emitting 900-MHz microwaves is similar to that obtained with 2450-MHz microwaves. Since the vast majority of thermotherapy devices use 915 or 1296-MHz microwaves, at a conceptual level these TUMT devices do not substantially differ and should therefore can be evaluated as one group.

Knowledge of the spatial distribution of the heat in the prostate is of paramount importance in order to achieve ablation of the transition zone and avoid undesired tissue injuries due to uncontrolled radiation. Therefore, the delineation of the radial and axial emission characteristics of antennas used to deliver energy to the prostate plays a key role in the choice of the appropriate antenna for a specific patient. Bolmsjö *et al*. performed an excellent study comparing the heat characteristics of three microwave antennas in a tissue-equivalent phantom prostate [21]. This phantom model absorbed only a part of the emitted energy, and this varied from 13% to 21% depending on the type of the antenna. It was suggested that the antenna design affects the heating pattern more than does the wave frequency [21].

Another operating characteristic of TUMT devices is the software protocol used to emit energy. Initial lower energy thermotherapy (LE-TUMT) protocols were clinically evaluated to confirm their safety and efficacy [22–24]. High-energy thermotherapy (HE-TUMT) was developed in accordance with the hypothesis that more energy should create higher temperatures and achieve a better clinical outcome. The higher-energy protocols result in a mean increase in the total energy delivered to the prostate of 40%, and in intraprostatic temperatures ranging between 45 and 80°C, which leads to coagulative necrosis that can create a prostatic cavity. It is logical that the more energy that is delivered, the more pronounced the thermoablative effect [25].

Another modification to the treatment protocols has been the heat-shock strategy in order to overcome the adaptation of the vessels to the slow increase of intraprostatic temperature, leading to resistance to the heat effects. The heat-shock strategy is characterized by a rapid build-up in power/temperatures that causes immediate vascular thromboses, resulting theoretically in a similar or better clinical outcome in a shorter duration of treatment [26].

Dispersion of heat by conduction in the tissue

The second step is determined by the tissue composition. The proportion of the various components of the prostate [epithelium-to-stromal ratio (E/S)] differs for each individual and this heterogeneity of the prostate histopathology has been suggested as the "intrinsic" factor responsible for the variability in clinical outcome, as each of the component reacts differently to microwaves. Microscopic examination has shown that acinar cells appear to be more resistant to heat than smooth muscle cells when exposed to the same temperature [27]. D'Ancona *et al*. correlated histologic findings from biopsy material with the therapeutic response to TUMT. No significant difference could be demonstrated for the tissue ratio between good and poor responders, despite the observation of a trend towards a lower E/S ratio in poor responders [28]. Furthermore, a large prostate has reported to be a favorable predictive factor for TUMT, because large prostatic volume appear to serve as a physical barrier to temperature distribution outside the gland, mainly to the rectal wall [25].

Blood flow

The third step is affected by the spatial and temporal variations of blood flow that affect thermotherapy outcomes and contribute to the lack of uniformity in clinical results [29]. Prostatic blood flow acts as a natural coolant, decreasing the intraprostatic temperature and delaying the coagulation mechanism [30]. The removal of thermal energy through the circulating blood (the theory of the "heat sink") affects the local effective temperature. Blood flow changes dynamically as treatment continues: at the beginning of the treatment, an increase in blood flow is usually seen, probably reflecting the vasodilation caused by the elevated temperature. Wagrell *et al*., using positron emission tomography (PET) to measure the intraprostatic blood flow, noted a rapid increase in blood flow up to 100% during the first 25–30 min of the treatment [31]. Towards the end of the treatment, blood flow decreases, most probably due to the occurrence of microthrombosis, with consequent capture of the heat in the exposed tissue causing faster coagulation necrosis. Floratos *et al*. studied the baseline intraprostatic vascularization using three-dimensional contrast-enhanced power-flow Doppler (3D-CE-PFD) prostate ultrasonography in a group of 22 patients treated with TUMT [32]. It was concluded that the baseline intraprostatic vascularization, documented by CE-PFD studies, has no predictive value for the efficacy of TUMT. It seems that "static" baseline blood flow does not reflect the "dynamic" thermoregulatory role of blood flow during treatment [32].

Optimal thermal treatment by temperature monitoring

Continuous monitoring of spatiotemporal intraprostatic temperature distribution would contribute to a better understanding of the basic mechanism of thermotherapy and tailoring of the treatment as well. Experimental studies have been conducted in order to evaluate the thermal mapping of the prostate, with the goal of understanding how to heat prostate. Several intraprostatic thermometry techniques have been proposed, including invasive and noninvasive methods. Interstitial thermal mapping in canine and human prostates using thermocouple arrays has been reported, but the invasive nature of the method makes it less attractive [9, 33, 34]. A less invasive method has been introduced and is commercially available [ProstaLund feedback treatment (PLFT)] [35]. PLFT continuously monitors the intraprostatic temperature using three sensors in a row on the needle-like temperature probe that protrudes through the catheter into one of the lateral prostatic lobes. Temperatures from the tip, mid, and apex of the prostate are considered to be recorded, allowing the operator to adjust manually the microwave power according to the actual measurements. The measured temperature is used to calculate the amount of necrotized tissue, by using a combination of the bioheat equation and cell survival data of thermal exposure [36].

Microwave radiometry thermometry is based on the thermal noise power, i.e. the electromagnetic radiation emitted by a given body whose temperature is raised. It has been clinically evaluated but it appears to have limited spatial resolution [37]. Magnetic resonance imaging (MRI) is temperature sensitive and this allows thermal mapping at the time of the treatment. Different MRI techniques have been used, including water diffusion, coefficient, T1 relaxation time, proton resonance frequency, and MR spectroscopic imaging [38]. Results suggest that MRI is a promising method because it offers good spatial localization and sufficient temperature sensitivity [39]. Ultrasound thermometry is another promising modality that is based on temperature-dependent acoustic tissue parameters, such as sound velocity, attenuation, back scattered power, and thermal expansion [40, 41].

The extent of tissue debulking due to coagulation necrosis may play a significant role in TUMT clinical outcome in terms of response and durability. Quantification in realtime of the amount of tissue ablated will allow treatment to be adjusted for each individual patient, and indicate when the desired volume has been destroyed and thermotherapy should be stopped. Bolmsjö *et al*. developed a cell-kill (i.e. tissue death) model to estimate the amount of the necrotized tissue, using both Henrique's damage integral and Jung's compartment model in a computer program [35]. In 22 patients treated with TUMT, the authors reported that cell kill was calculated with reasonable accuracy compared to transrectal ultrasound (TRUS)-determined volume reduction 3 months after TUMT. This cell-kill model has been integrated into the ProstaLund treatment software. Nordling *et al*. concluded from a prospective randomized multicenter study on 100 patients treated with PLFT that the calculated cell kill was a valid and good predictor to determine when to stop treatment [42].

Gadolinium-enhanced MRI has been used to determine the extent and pattern of coagulation necrosis caused by TUMT. Osman *et al*. treated 13 patients using the Targis device (Urologix, Minneapolis, MN, USA) and performed a post-treatment MRI [43]. Necrotic tissue presented as a perfusion defect that accurately correlated with the prostatic tissues exposed to temperatures of 45°C or greater for at least 45 min. Huidoro *et al*. investigated the intraprostatic heat distribution and the relation to histopathology, MRI, and cell-kill calculations using the CoreTherm TUMT device (ProstaLund, Lund, Sweden). Microwave treatment caused necrosis of the prostate, bladder neck, and urethral mucosa, and the tissue necrosis assessed by pathology, MRI, and cell-kill calculation was comparable [44]. Recently, Vesely *et al*. confirmed that the CoreTherm device causes distinct intraprostatic necrosis detectable by MRI and reliably predicted by the cell-kill calculation. Perfusion of the prostate before the treatment was not shown to have any impact on treatment parameters [45]. On the other hand, using diffusion-weighted MRI before treatment, it was found that the apparent diffusion coefficient (ADC) value, which characterizes the microstructure of the prostate, correlated strongly with the treatment parameters. More specifically, prostates with a lower ADC, and thus a more complex structure, needed a significantly higher amount of energy and a longer time to achieve a desirable amount of necrosis [45].

Translation into clinical practice: TUMT devices

Based on the described principles of microwave thermotherapy, several devices operating at either 915 MHz or 1296 MHz with different microwave antenna designs, cooling systems, treatment times, and monitoring of TUMT effect have been introduced. The main players in the field of microwave thermotherapy are the Prostatron® device (Urologix), Targis® (Urologix), CoreTherm® (ProstaLund), the TMx-2000® (TherMatrx Inc, Northbrook, IL, USA).

Prostatron first used the first-generation, low-energy Prostasoft 2.0 software, followed by the Prostasoft 2.5 high-energy software. Later, 30-min high-energy software was developed, the Prostasoft 3.5 protocol. The CoreTherm system provides intraprostatic temperature monitoring. The measured temperature is used for real-time calculation of the amount of necrotized tissue,

Table 124.1 Clinical outcome from a systematic review and meta-analysis of randomized clinical trials comparing transurethral microwave thermotherapy (TUMT) with transurethral resection of the prostate (TURP) and pooled data of ProstaLund feedback treatment (PLFT).

			IPSS			Qmax (mL/s)		
Study	Treatment	Paients (n)	Baseline	12-month follow-up	Mean difference (95% CI)	Baseline	12-month follow-up	Mean difference (95% CI)
Hoffman *et al.* [49]	TUMT	322	19.4	6.7	−1.83 (−3.09 to −0.58)	7.9	13.5	5.44 (4.22–6.51)
	TURP	218	19.6	4.5		8.6	18.7	
Kaye *et al.* [50]	HE-TUMT	NA	NA	NA	−3.34 (−4.67 to 2.01)	NA	NA	7.05 (5.48–8.63)
	TURP	NA	NA	NA		NA	NA	
Gravas *et al.* [51]	PLFT	183	20.9	6.4	NA	7.7	16.1	NA
	TURP	65	20.7	7.1		7.5	18.6	

IPSS, International Prostate Symptom Score; Qmax, maximum urinary flow rate; NA, not available.

using a combination of the bioheat equation and cell survival data of thermal exposure. Consequently, the system allows tailoring of treatment to the needs of each patient. Targis is a high-energy cooled thermotherapy system. In addition, a third-generation Urologix system, the Cooled ThermoCath (CTC), which uses a 28.5-min treatment at higher temperatures, has also been developed. The TherMatrx TMX-2000 differs from other available microwave device systems in that it lacks a cooling system and uses a lower wattage.

Efficacy of TUMT

Numerous studies have been published presenting the clinical results from the application of TUMT. These studies have used different devices with different treatment protocols, and have had different follow-up periods. Generally, studies on BPH treatment use the improvement in maximum urinary flow rate (Qmax) and changes in International Prostate Symptom Score (IPSS) as the objective and subjective outcome measures, respectively. The objective and subjective improvements of the initial LE-TUMT protocols have been proven in prospective randomized sham-controlled studies [46–48]. In addition, HE-TUMT-protocols were developed, further reinforcing the meaningful response to therapy being greater than the sham effect of instrumentation. A systematic review analyzed data from 850 participants (523 treated with TUMT and 327 sham controls) in seven randomized trials [49]. The TUMT group had greater improvement in symptom scores than the sham control group. The pooled mean IPSS for men undergoing TUMT decreased by 50% in 3–6 months (21.4–10.8) versus 41% (21.3–12.6) in the men undergoing sham treatment. Similarly, Qmax improved slightly more following TUMT compared to sham treatment: 1.7 mL/s (95% CI 1.0–2.3). The pooled mean Qmax for patients undergoing TUMT increased 43% (from 8.1 mL/s to 11.6 mL/s) versus 11% (from 8.7 mL/s to 9.7 mL/s) in men undergoing sham treatment [49].

In the evaluation of minimally invasive treatments for BPH, the results of each new therapy need to be compared with those obtained with conventional surgical procedures, namely TURP. Recently, a Cochrane systematic review of all available randomized controlled trials (RCTs) on TUMT attempted to quantify its therapeutic efficacy [49] (Table 124.1). Treatment was with different TUMT devices and software, including Prostatron (Prostatsoft 2.0 and 2.5) and ProstaLund Feedback. Overall, of 540 patients 322 were randomized To TUMP and 218 to TURP in the six eligible randomized studies. Weighted mean differences (WMD) were calculated with 95% CI for the between treatment differences in pooled means. TUMT was somewhat less effective than TURP in reducing LUTS. The pooled mean symptom score for men undergoing TUMT decreased 65% in 12 months (19.4 to 6.7) compared with 77% (19.6 to 4.5) in men undergoing TURP, with a WMD for the symptom score of −1.83 (−3.09 to −0.58), favoring TURP [49]. TURP achieved a greater improvement in Qmax (119%) than TUMT (70%), and the calculated WMD was 5.44 (4.22–6.51) mL/s in favor of resection at the 12-month follow-up [49]. The mean Qmax after TUMT was generally less than 15 mL/s: only two studies reported a mean Qmax following TUMT greater than 15 mL/s, while five studies reported that TURP achieved a mean Qmax greater than 15 mL/s. No statistically significant difference for improving urinary symptom scores or peak urinary flow could be detected between the different devices [49].

Similar clinical outcomes have been reported Kayne *et al.* in a recent meta-analysis of the available RCTs comparing HE-TUMT with TURP [50]. This meta-analysis calculated a summary mean difference of continuous variables, including IPSS, Qmax, and postvoid residual (PVR) for 458 patients. Twelve months after treatment, changes in Qmax ($P < .001$), IPSS ($P = .01$), and PVR ($P = .02$) were more significant for TURP than TUMT (Table 124.1). Interestingly, when data were stratified according to the TUMT device, the CoreTherm device (PLFT system) demonstrated the most significant improvements in subjective and objective criteria [50].

Gravas *et al*. performed a pooled analysis of three studies of the ProstaLund Feedback TUMT device with 12-month follow-up [51]. Two randomized studies comparing PLFT to TURP and an open-label study with no comparative group were combined. Inclusion and exclusion criteria for the three studies were identical and this fact reduced any selection bias. A total of 248 patients were studied; 183 were treated with the PLFT and 65 with TURP. The responder rates were 85.3% and 85.9% in the PLFT and TURP groups, respectively [51]. One-sided 95% CI analysis showed noninferiority of PLFT as compared to TURP. A "responder" was defined as a patient who following treatment had an IPSS of 7 or less, and/or 50% or greater improvement in IPSS from baseline, and/or a Qmax of 15 mL/s or more, and/or 50% or greater improvement in Qmax from baseline [51]. In addition, there was a marked decrease from a mean IPSS of 20.9 at baseline to 6.4 at 12 months after TUMT, which is a decrease of 69% compared to baseline (Table 124.1). In the TURP group, mean IPSS was decreased from 20.7 at baseline to 7.1 at the 12-month visit (a 66% change). The one-sided CI (95%) for the ratio of IPSS between the PLFT and TURP groups suggested noninferiority of PLFT compared to TURP treatment. In the PLFT group, the mean Qmax improved from 7.7 mL/s at baseline to 16.1 mL/s at 12-month follow-up, corresponding to a 109% increase (Table 124.1). In the TURP group, Qmax increased from a mean value of 7.5 mL/s at baseline to 18.6 mL/s at the end of treatment (a 148% change). However, although both treatment modalities significantly improved Qmax, one-sided 95% CI analysis showed that noninferiority of PLFT as compared to TURP did not reach the predetermined level. This pooled analysis indicated that PLFT appears to have an efficacy that in terms of IPSS and responder rate is noninferior to TURP [51].

Patients in urinary retention

The indication for microwave treatment has gradually changed from patients with solely irritative symptoms to now include patients with evident obstructive elements and patients in urinary retention. Men in retention represent a specific group of benign prostatic obstruction (BPO) patients; in general, they are at increased risk of perioperative morbidity and mortality and present a lower response to any treatment that resolves obstruction [52]. In the past, urinary retention was considered as a contraindication for TUMT but today urologists feel more confident to offer this minimally invasive option to patients in retention due to the advanced devices and treatment protocols.

Level 2b evidence studies have reported a success rate for TUMT (defined as the percentage of patients who regained their ability to void spontaneously) ranging from 80% to 93% (Table 124.2) [53–58]. However, these studies had a very short follow-up (≤12 months), making it difficult to estimate the durability of TUMT outcome in patients with retention. Floratos *et al*. estimated the 1-year retreatment rate to be 25% [59]. In a study of 213 patients (45 in retention) treated with the Prostasoft 3.5 and followed-up for up to 5 years, it was found that the treatment failure rate was 37.8% in the retention group [60]. The cumulative risk at 5 years was 58.8% for patients in retention, while the corresponding risk for patients without retention was 42.3% ($P = .03$), indicating that the risk of retreatment is higher for patients in retention prior to TUMT [60].

Table 124.2 Efficacy of transurethral microwave thermotherapy on patients in retention.

Study	Treatment	Patients (n)	Success rate (%)	Comments
Djavan *et al.* [53]	Targis	31	94	
Naqvi *et al.* [54]	Prostasoft 2.5	167	92.8	Acceptable Qmax
Schelin *et al.* [55]	PLFT	24	80	Failure due to median or protruding lateral lobes
Kellner *et al.* [56]	Targis	39	82	Only six were able to stop medication for BPH
Berger *et al.* [57]	Targis	78	87.1	Patients in poor general health
Schelin *et al.* [58]	PLFT	61	79	Only randomized controlled trial against TURP/open
	TURP/Open	59	88	

PLFT, ProstaLund feedback treatment; TURP, transurethral resection of the prostate; Qmax, maximum urinary flow rate.

Table 124.3 Long-term results from randomized controlled trials and a pooled analysis of transurethral microwave thermotherapy (TUMT) studies.

				IPSS			Qmax (mL/s)		
Study	Treatment	Patients (n)	Follow-up (months)	Baseline	12-months	End	Baseline	12months	End
d'Ancona *et al.* [63]	TUMT[1]	31	30	18.3	5.7	7.9	9.3	17.1	15.1
	TURP	21		16.7	3.4	6.3	9.3	19.3	19.1
Floratos *et al.* [64]	TUMT[1]	78	36	20.0	8.0	12.0	9.2	15.1	11.9
	TURP	66		20.0	3.0	3.0	7.8	24.5	24.7
Mattiasson *et al.* [65]	TUMT[2]	99	60	21.0	7.2	7.4	7.6	13.3	11.4
	TURP	46		20.4	7.1	6.0	7.8	15.2	13.6
Trock *et al.* [66]	TUMT[3]	541	48	20.9	9.5	11.5	7.9	11.5	10.9

[1] Prostatron/Prostasoft 2.5.
[2] Coretherm PLFT.
[3] Targis cooled thermotherapy.

TUMT versus medical therapy

The position of TUMT versus medical therapy for the management of LUTS with BPO has also been evaluated by Djavan *et al*. in an RCT of 103 patients treated with either targeted TUMT or with terazosin [61]. The mean IPSS improved significantly from baseline by 6 months in both groups, but men treated with TUMT had significantly greater symptom relief as measured by the IPSS (WMD –4.20, 95% CI –5.25 to –3.15) and improvement in peak urinary flow (WMD 2.30 mL/s, 95% CI 1.47–3.13). The percentage of TUMT patients having a 50% or greater increase in Qmax and IPSS at 6 months (64.7% and 78.4%, respectively) markedly exceeded that in the terazosin group (9.6% and 32.7%, respectively). In an update of the study on TUMT versus terazosin, patients had been followed-up for 18 months [62]. The subjective and objective improvement observed at 6 months was maintained at 18 months, and was significantly greater in the TUMT group compared to the terazosin group (by 35% and 22%, respectively). By 18 months, 21 patients had failed terazosin therapy: in 13 it was ineffective and in eight because of side effects. Three patients failed TUMT by 18 months and proceeded to surgery [62]. The actuarial rate of treatment failure at 18 months in the terazosin group (41%) significantly exceeded that of the TUMT group (5.9%), resulting in a significantly lower risk of retreatment for men treated with TUMT (RR 0.12, 95% CI 0.04–0.38; RD –0.43, 95% CI –0.27 to –0.59).

Durability

Besides favorable short-term outcome, durability of long-term improvements is prerequisite for acceptance of TUMT and therefore subjected to investigation. TUMT has been criticized for the lack of high-quality studies on its durability. In general, most of the studies vary in follow-up duration and are characterized by a significant attrition rate. Consequently, less than half of the initial group of patients treated is analyzed at 4–5 years in terms of Qmax and IPSS, and these patients are likely to represent the best responders. Reviewing the randomized long-term trials comparing HE-TUMT to TURP, it is found that improvement in urinary flow rate remains stable at 6 and 12 months follow-up, but there is some deterioration after 2.5 years [63–65]. The maximum improvement in IPSS is obtained 3 months after treatment and the subjective improvement remains significant and durable for more than 30 months after TUMT, despite a slight increase in IPSS. A similar trend is observed for patients treated with TURP, but the magnitude of improvement is greater. Table 124.3 summarizes the long-term results from RCTs and a pooled analysis of TUMT studies [63–66].

Retreatment rate, defined as the percentage of patients undergoing any additional therapy for the primary treatment failure, represents an important parameter for the evaluation of treatment durability. Retreatment of TUMT is related to treatment failure whereas retreatment of TURP is related to complications of resection.

LE-TUMT has shown disappointing results in terms of durability, with several studies reporting a retreatment rate of up to 84.4% after 5-year follow-up [67–69]. Reported retreatment rates after HE- TUMT range from 19.8% to 29.3%, but with different mean follow-up durations (from 30 to 60 months) [63, 64, 66, 70]. In the systematic review of randomized trials described above, Hoffman *et al*. estimated the retreatment rate due to treatment failure, expressed as the number of events per person per year of follow-up [49]. It was found that TUMT patients (7.54 events/person-years) were more likely than TURP patients (1.05/100 person-years) to require additional treatment for BPH symptoms, while in contrast the retreatment rate for strictures (meatal, urethral or bladder neck) was found to be 5.85/100 person-years and 0.63/100 person-years for the TURP and TUMT groups, respectively [49].

Tsai *et al.* reported the 5-year results of a prospective randomized multicenter study comparing TUMT with the CoreTherm device (PLFT; ProstaLund) to TURP [67]. No statistically significant differences were found between the two treatment groups in Qmax and IPSS at 60 months. In the TUMT group, 10% needed additional treatment versus 4.3% in the TURP arm. These data suggest that at 5 years, clinical results obtained with PLFT TUMT were comparable to those seen after TURP [67].

TUMT as an outpatient procedure: tolerability, safety, and morbidity

Unlike TUMT, for TURP spinal or general anesthesia is a prerequisite. TUMT treatments are usually well tolerated by patients. Perception of discomfort varies from a mild feeling of perineal warmth and a mild urge to urinate to occasional significant discomfort. Distraction and reassurance are usually enough, but momentary interruption of microwave emission may be useful in those cases where major discomfort is experienced. In contrast to lower-energy protocols, pain medication needs to be administered in a higher number of patients prior to or during HE-TUMT [71]. In a Food and Drug Administration (FDA) trial, regional and general anesthesia was required in 32% of patients, oral sedation in 19%, and parenteral sedation in 12% [72]. The need for sedoanalgesics in every patient has been questioned. A randomized comparison of topical urethral anesthesia alone versus topical anesthesia with adjunctive intravenous sedoanalgesia showed that the former was well tolerated by patients, thus avoiding the risks of sedoanalgesics during treatment [73].

Schelin studied the effects of intraprostatic and periprostatic injection of mepivacaine epinephrine prior to TUMT [74]. He concluded that the administration of mepivacaine epinephrine seems to have beneficial effect on treatment time, required energy, and intraprostatic blood flow, and improves patient comfort [74]. Similarly, Knutson *et al*. found that intraprostatic injection of mepivacaine epinephrine results in a significant decrease in the number of patients requiring intravenous analgesia (11% of the intraprostatic injections group vs 70% of patients without intraprostatic injection). In addition, it was concluded that, besides increased patient comfort, this technique may also reduce the treatment time without decreasing treatment success, thereby making PLFT treatment more manageable in outpatient practice [75].

Larson *et al.* performed a retrospective study to investigate the occurrence of adverse blood pressure events during TUMT using all six FDA-approved devices with different anesthetic/analgesic protocols [76]. Approximately half of the patients undergoing TUMT showed marked and acute blood pressure increases. The stratified results showed variability among the TUMT devices used for treatment. The mechanisms responsible for these surges and the causes of these variations could not be identified. These data indicate that blood pressure should be monitored and, treatment adjusted, and antihypertensive medications continued during all TUMT procedures [76].

Pooled data of the published randomized studies comparing TUMT and TURP regarding morbidity indicate that the main advantage of TUMT is its low morbidity [49, 77, 78] (Table 124.4). Prolonged catheterization, dysuria or urgency, and urinary retention were the most frequent adverse events after TUMT. For patients treated with TURP, the mean length of hospitalization and catheterization time was 4.0 days and 3.6 days, respectively, and the corresponding mean values for TUMT were 0 days and 13.7 days. The incidence of hematuria, clot retention, transfusions, and TUR syndrome was reported to be significantly lower for TUMT than for TURP. The impact of TUMT on sexual function in terms of erectile dysfunction and retrograde ejaculation has also been studied in comparison to TURP, with pooled data favoring TUMT. The surgical retreatment for urethral strictures and/or bladder neck contracture has also been found to be significantly higher for TURP (5.85/100 person-years) than for TUMT (0.63/100 person-years), with a relative hazard of 9.76. [49].

A variety of other rare but reported complications following TURP occur. These includes, but are not limited to, bladder perforation, urethrovesical fistula, and emphysematous, prostatic abscess. The FDA has published safety recommendations for the use of TUMT devices [79].

Consequently, TUMT is considered as a true outpatient procedure due to its low morbidity and lack of need for any anesthesia (spinal or general), and thus represents an excellent option for patients with high operative risk [80].

Outcome predictors

Although thermotherapy is an effective modality for the management of LUTS suggestive of bladder outlet obstruction, a considerable number of patients fail to achieve satisfactory relief of symptoms. Therefore, the burning question regarding TUMT is how to select patients who will respond favorably to heat therapy. The ideal patient for this modality has yet to be fully characterized. Controversial results have been reported

Table 124.4 Pooled data from randomized controlled trials on morbidity following transurethral microwave thermotherapy (TUMT) and transurethral resection of the prostate (TURP).

	de la Rosette [77]		Walmsley and Kaplan [78]		Hoffman [49]		
Variables	TUMT	TURP	TUMT	TURP	TUMT	TURP	RR (95% CI)
Hospitalization time (days)	0.0	4.0 (3.9–4.1)	0.0	2.8 (1.0–4.1)	NA	NA	NA
Catheterization time (days)	13.7 (12.7–14)	3.6 (3–4.1)			NA	NA	NA
Urinary tract infections (%)	14.6 (3.3–18)	13.1 (4–20)	9.0 (3–19)	6.0 (5–9)	17.7	13.9	1.15 (0.70–1.86)
Dysuria (%)			51.0 (12–99)	15.0 (9–23)	31.2	13.1	2.22 (1.28–3.86)
Retention (%)	NA	NA	15.0 (1–33)	5.0 (4–8)	23.9	6.9	2.94 (1.52–5.70)
Transfusions (%)	NA	NA	1.5 (0–9)	8.0 (5–11)	0.0	5.7	0.11 (0.01–0.86)
TUR syndrome (%)	NA	NA			0.0	6.1	0.13 (0.02–0.81)
Erectile dysfunction (%)	4.4 (0–6)	9.3 (0–21)	8.7 (0–8)	10.0 (7–13)	5.7	13.9	0.41 (0.16–1.05)
Retrograde ejaculation (%)	19.8 (0–33)	63 (50–80)	20.0 (2–49)	65.0 (56–72)	22.2	57.6	0.39 (0.21–0.75)
Urethral/bladder neck strictures (%)	0.7 (0–2.8)	9.6 (4.8–15.6)	2.0 (0–9)	7.0 (5–8)	0.0	9.5	0.13 (0.02–0.71)

1 – 2 NA, not available.

regarding whether or not prostate size, severity of symptoms, or baseline serum PSA levels can predict clinical outcome of microwave heat therapy, and this represents a source of disagreement among authors. It is very difficult to identify predictive baseline parameters for TUMT, since different devices have been used and studies suggest that a predictive factor for one particular device is not necessarily of value for other devices [81]. However, advanced patient age, small prostate volume, mild-to-moderate bladder outlet obstruction, and a low amount of energy delivered during treatment are considered to be independent baseline parameters predicting an unfavorable outcome [82].

Cost

The introduction of new technology in healthcare is sometimes charged as one of the major causes of escalating costs due to the purchase of the capital equipment and failure in terms of efficacy, morbidity, and durability. Different economic models evaluating the cost-effectiveness of minimal invasive therapies for BPH have been introduced [83, 84]. However, the cost-effectiveness of all techniques depends on the existence of long-term data, costs of complications or retreatment, and the different reimbursement systems in different countries. Therefore, it is difficult to draw solid conclusions that are applicable to every country.

When applying the different models, it seems that TUMT is cost saving and a reasonably cost-effective alternative to both TURP and medical therapy for treatment of moderate-to-severe BPH [83, 85]. Savings also depend on the number of men who seek treatment for BPO [86]. The initial fixed cost of TUMT compared to TURP is compensated by the large treatment capacity, which lowers the relative cost per patient. DiSantostefano evaluated the incremental cost-effectiveness of BPH treatment alternatives [87]. He used a Markov model over a 20-year time horizon and the payer's perspective to evaluate the cost-effectiveness of watchful waiting (WW), pharmaceuticals (alpha-blockers, 5-alpha-reductase inhibitors, combination therapy, TUMT, and TURP) in the management of BPH. It was found that alpha-blockers and TURP appear to be the most cost-effective alternatives, from a US payer perspective, for BPH patients with moderate and severe symptoms, respectively. TUMT was promising for patients with moderate symptoms and the oldest patients with severe symptoms, but for other patient groups other therapies were more cost-effective [87].

In general, performance of treatment on an outpatient basis represents a critical factor that reduces the direct cost and renders TUMT economically advantageous compared to surgical treatments. However, this benefit may be balanced by the higher retreatment rate of TUMT.

Current position of TUMT

Data from the Urologic Diseases in America BPH project showed that BPH therapy trends are moving away from the gold standard operation of TURP and toward less invasive pharmacologic options and minimally invasive therapy in an outpatient setting [88]. In addition, the aging of the population has resulted in longer waiting lists and a growing demand for effective and cost-worthy alternatives. Into this frame, TUMT is one of the best studied minimally invasive therapies and high quality data are available. Based on these data, the European Association of Urology (EAU) Guidelines state that TUMT is considered as the most attractive interventional modality alternative to TURP, and should be reserved for patients who want to avoid surgery or do not respond favorably to medication [89]. According to the American Urological Association (AUA) Guidelines, TUMT is effective in partially relieving symptoms in BPH patients, but there is no evidence of superiority of one device over another [90]. The 6th International Consultation on New Developments in Prostate Cancer and Prostate Diseases concluded that TUMT has good clinical outcomes that seem durable and low morbidity, and it represents an option when instrumental treatment is indicated (except when an absolute indication for surgery exists) [91].

However, in spite of many well-conducted positive studies, the better understanding of thermotherapy and the sufficient clinical documentation, the clamor from the acceptance of TUMT in daily clinical practice is not pertinently loud. Plausible reasons include the fact that initial enthusiasm for most of the minimally invasive alternative treatments often fades away with time, and the development of new technologies for BPH treatment. In addition, there is a significant difference in acceptance of TUMT between Europe and the USA. A survey performed in 2001 during the EAU meeting showed that only 18.5% of 854 European participants had already had access to TUMT [92]. However, when asked what kind of equipment they would like to have access to among the alternative minimally invasive techniques, 40% preferred the holmium laser, 11% electrovaporization, 5% transurethral needle ablation (TUNA), 5% TUMT, 4% Gyrus, and 3% interstitial laser coagulation, while 61.5% of the respondents did not choose any of the proposed equipment. It was considered that these results reflected urologists' satisfaction with the devices to which they had access, different fields of interest or misbeliefs in the clinical potential of alternative treatments [92]. Recently, Yu *et al*. performed an important Medicare-based study and showed that the total rate of BPH procedures increased significantly after 2002 due to the marked increase of new minimally invasive surgical treatment procedures [93]. By 2005, these represented 57% of total BPH surgeries in the USA, while TURP represented only 39% (vs 81% in 1999). The most commonly performed minimally invasive surgical treatment in 2005 was TUMT (22.7% of all BPH procedures). Furthermore, reimbursement policy encourages outpatient management of urologic diseases. A review of the 2008 Medicare fee schedule physician reimbursement for TUMT indicates an approximate value of $2901.75 in the office site of service and $536.34 for a hospital-based procedure [94]. In addition, it has been reported that while in 1999, 83% of TUMTs were performed in the hospital outpatient setting, by 2005 almost all TUMTs (98.9%) were performed in clinician offices [93]. This high in-office reimbursement of TUMT relative to TURP, availability of TUMT devices, and patient preference may have driven the move to the office/outpatient setting where TUMT dominates, and this may explain the discrepancy between the use of TUMT in Europe and in the USA.

Conclusions

TUMT is established as a safe and effective minimally invasive alternative to treat symptomatic BPH, but it is not as effective as TURP. However, given the low morbidity of TUMT, a higher risk of retreatment may be a reasonable trade-off for patients with LUTS due to BPH. In addition, there are different approaches regarding the adoption of TUMT in clinical practice, depending on local conditions of reimbursement, an institution's financial support, and personal preferences. Into this frame, TUMT tailored to selective cases remains an attractive option.

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CHAPTER 125

Transurethral Needle Ablation of the Prostate

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Introduction

Surgical therapy, despite being considered the "gold standard" treatment for lower urinary tract symptoms (LUTS) secondary to benign prostatic hyperplasia (BPH) in the past, is now considered second-line therapy and is usually reserved for patients who have failed medical therapy or minimally invasive treatments, or patients with absolute indications for surgery. The number of minimally invasive surgical treatment procedures for BPH from 1999 through 2005 among elderly male Medicare beneficiaries increased 529%, and the transurethral resection of the prostate (TURP) rate decreased approximately 5% per year. By 2005, minimally invasive surgical treatment procedures accounted for 57% of total BPH surgeries, while transurethral prostate resection accounted for only 39% [1].

Transurethral needle ablation (TUNA) is an office-based minimally invasive therapy, first introduced in 1993 by the Ed Stewart-Vidamed Company. It relies on delivering energy via a radiofrequency (RF) generator, an optical transurethral device, and two needles that allow selective necrosis of tissue. The TUNA system delivers low-level RF energy through the two needles inserted into the prostate and thermally ablates a well-defined region of the enlarged prostate. Teflon shields were used from the very beginning of the TUNA technique to protect the urethra from heat damage. There has been a constant evolution in the equipment since initial reports.

The initial idea in the early 1990s came from the rationale that if RF is safe enough to selectively ablate aberrant heart bundles responsible for cardiac arrhythmias, it could be safe enough to ablate hypertrophic benign prostatic tissue. Interestingly, catheter ablation therapy for arrhythmias has also evolved over the past 20 years to become the first-line therapy, facilitated by technology that has allowed better anatomic and electrophysiologic correlations. A better understanding of RF ablation has led to safer and more effective treatments, and this has become a potent diagnostic and therapeutic tool in clinical cardiac electrophysiology [2].

TUNA has now been for many years an accepted therapy for the treatment of LUTS due to BPH. In October 1997, the Food and Drug Administration (FDA) approved the TUNA system for the treatment of BPH. The TUNA® system (Medtronic Inc, Minneapolis, MN, USA) and the TUNA Office System, an updated version of the original system, received 510K approval from FDA as a Class II device in February 2001. In November 2005, the FDA granted 510K clearance for the Prostiva™ RF Ablation System, stating that it is substantially equivalent to TUNA® Therapy (the previous name for this product), and this remains the only currently FDA-approved TUNA system in the USA.

In the UK, guidance on the safety and efficacy of interventional procedures is produced by the Interventional Procedures Program within the National Institute of Health and Clinical Excellence (NICE) [3]. In October 2003, NICE issued guidance on the use of

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TUNA for the treatment of benign prostatic obstruction (BPO). According to the NICE guidance, the literature demonstrated that TUNA was a safe procedure with fewer postoperative complications (e.g., bleeding) than TURP and was efficacious in the short term. The guidance noted that the current evidence was adequate to support the use of TUNA in the treatment of BPO provided the normal arrangements are in place for consent, audit, and clinical governance. The long-term efficacy has yet to be established though [3].

The American Urological Association (AUA) guidelines [4] state that TUNA is effective in partially relieving the symptoms of BPH. For the relief of symptoms in the average patient, TUNA appears to be more effective than medical therapy but less effective than TURP. The ideal patient for this procedure is a man who has obstructive BPH, a prostate of 60 g or less, and predominantly lateral lobe enlargement.

In France, TUNA has been recommended by the Haute Autorite de Sante (HAS) since its report in 2006 [5].

Part of the difficulty in assessing clinical practice guidelines is the differences in methodology and rigor of development that can lead to varying recommendations (e.g. several recommendations of the European Association of Urology guidelines [6] differ from those of the AUA guidelines). Nevertheless, clinical practice guidelines provide a framework for discussion and should be used in the context of overall healthcare delivery.

The advantages of the TUNA procedure over the more invasive surgical resection are the ease of performance in an outpatient setting with minimal anesthesia and avoiding the major complications of the transurethral resection procedure. In addition to relief from the bothersome symptoms, preservation of a certain quality of life and sexuality are very important for patients as well.

This chapter will review the TUNA procedure, evolution in technique and equipment, clinical outcome, long-term efficacy, and side effect profile.

Principles of thermal ablation techniques

Many different minimally invasive thermal ablative techniques have been described for treating benign and malignant tumors. The principal mechanism of tissue necrosis is the same and does not depend on the frequency of the electromagnetic energy, i.e. whether radiowaves, microwaves or visible light, but the frequency determines the extent of the uptake and dissipation in the tissue. The heat generated (in Joules) is a product of the power applied (in Watts) and duration of application (minutes and seconds), and its diffusion is related to the impedance of the tissues treated. All thermal effects are influenced negatively by blood flow, as this removes heat before the tissue is completely ablated (the heat-sink effect); this effect protects blood vessels and prevents bleeding of large vessels, and is a reason for incomplete ablation, which may be an important concern in oncology, e.g. in renal tumor ablation. This is certainly less of a concern in BPH.

With TUNA, low-level RF energy (473 kHz) passes from two active electrode (needles) to the prostatic tissue, then to the ground pad in a monopolar fashion, and then back to the generator. RF energy allows greater control and more uniform temperature distribution than microwaves (300–3500 MHz). When the RF energy meets tissue resistance, it is converted into thermal energy via molecular agitation (direct heating). Heat is conducted further into the tissue via "cell-to-cell" conductive heating. The amount of heat energy produced and the subsequent thermal effect are determined by the amount of tissue contact (length of the needle) and power level (wattage). Temperatures above 50° C cause coagulative necrosis of tissues following a well-defined "time–temperature" toxicity curve [7–9].

TUNA (Prostiva RF System) achieves temperatures of greater than 100° C in selected areas of the prostate and core temperatures of around 115° C. The TUNA cartridge consists of a specialized cystoscope connected to a RF generator. Two flexible needles, which can be deployed at an acute angle of 40° to each other and at 90° to the catheter, emerge at the bullet-shaped catheter tip for an adjustable length of 12–22 mm that the urologist will adapt depending on the gland size and shape. The originality of TUNA as compared to other minimally invasive procedures lies in the Teflon shields that cover the base of the needles in order to protect the urethra from high temperatures. The rationale is to produce necrotic lesions inside the prostate parenchyma while trying to spare prostatic anatomy (both the urethra and prostate capsule) in order to minimize postoperative side effects. An optical path within the catheter allows the accurate positioning of the catheter within the prostate under direct vision, similarly to any cystoscopic procedure.

Evolution of techniques and equipment

The TUNA procedure (S Edwards, Vidamed Company, Palo Alto) was introduced in the early 1990s, followed in several countries by first investigations in animals and humans. In Israel, Goldwasser and Ramon demonstrated large necrotic lesions with TUNA of the canine prostate and in *ex vivo* human prostates [10, 11]. At the same time in Belgium, and for the first time in humans, Schulman *et al.* performed a pilot study in patients to evaluate TUNA feasibility, safety, and histopathologic assessment of thermal lesion size by: (1) monitoring ure-

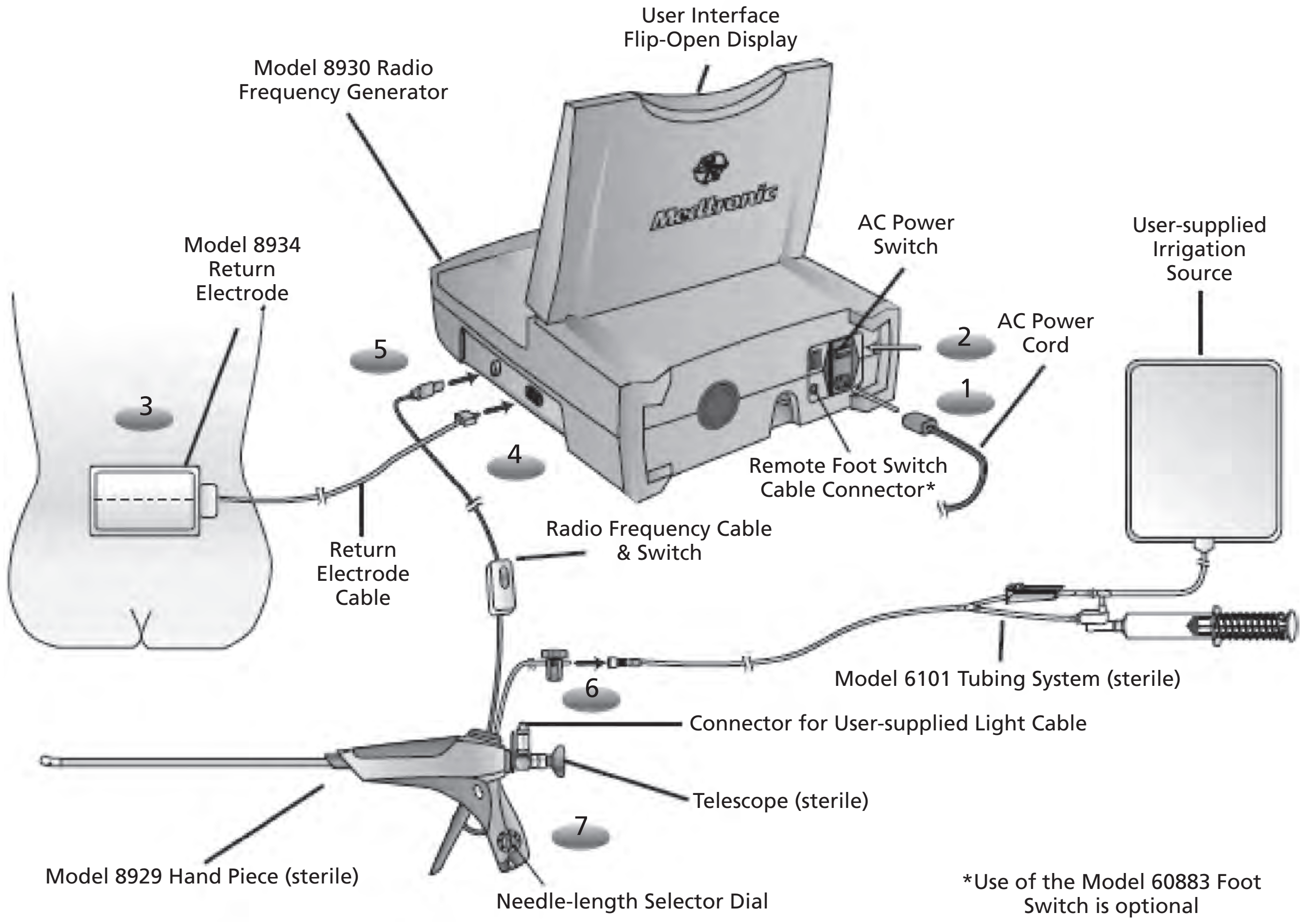

User Interface
Flip-Open Display
Model 8930 Radio
Frequency Generator
Model 8934
Return
Electrode
AC Power
Switch
User-supplied
Irrigation
Source
AC Power
Cord
2
1
5
3
4
Remote Foot Switch
Cable Connector*
Radio Frequency Cable
& Switch
Return
Electrode
Cable
Model 6101 Tubing System (sterile)
6
Connector for User-supplied Light Cable
Telescope (sterile)
7
Model 8929 Hand Piece (sterile)
Needle-length Selector Dial
*Use of the Model 60883 Foot
Switch is optional

Figure 125.1 Current systems (courtesy of Medtronic).

thral and rectal temperatures; (2) assessing the ability to localize lesions; and (3) determining patient tolerance of the procedure without anesthesia [12]. Twenty patients were treated using TUNA prior to scheduled retropubic prostatectomy. The surgical prostatic specimens were recovered from 1 day to 1 month after TUNA, step-sectioned, and examined histologically. The TUNA procedure averaged 27 min (far longer than today), four lesions were produced per prostate, and 4–15 W of power were applied for 3 min. The proximal lesion temperature was about 40–50°C with central lesion temperatures of about 80–100°C. Urethral temperature averaged 37–42°C and rectal temperature remained unchanged. Macroscopic examination of the specimens demonstrated localized lesions averaging 12 × 7 mm. Microscopic examination showed lesions of extensive coagulative necrosis averaging 30 × 15 mm. Immunohistochemical staining showed destruction of all tissue components, including adrenoreceptors [12]. An infrared thermal gradient mapping and comparison of lesion sizes in a tissue model and in patients with BPH were also performed [7].

The early clinical experience and feasibility of TUNA (using the first-generation technology) under local anesthesia was published by Schulman and Zlotta [13]. Results were confirmed by several groups in the mid/late 1990s in Israel, Italy, South Africa, the UK, Canada, Australia, the USA, Sweden, Ireland, Israel, Norway, and Germany [14–26]. These initial reports showed that TUNA of the prostate appeared to be a simple, safe (very few side effects, especially on sexual function and urinary continence), and efficacious procedure for treatment of symptomatic BPH, given without general or spinal anesthesia and using only topical urethral anesthesia or local prostatic block. They also confirmed the extent of the lesions produced. However, the technique and equipment used clearly required improvements and it was hoped and anticipated that these would also translate into improved outcomes. In addition, most of these studies were non-randomized.

Figure 125.1 illustrates the evolution in technique and equipment since TUNA's early development phases. We first used TUNA in 1993, in purely ultrasound-guided models without optics. There has been a constant evolution in the development of TUNA generators and catheters since the first generation was launched in 1993 (22–26G needles).

With the first models, direct visualization of the needles was not possible when deploying them into the prostatic tissue. Temperatures were read by thermosensors placed not at the tip of the needle but on the shields of the needles that were deployed, and thus at the periphery of the lesion in the making. They could not be measured at the tip of the needle, and therefore at the center of the lesion, because needles at that time were not hollow. The power delivered had to be adapted manually according to the impedance of the tissue. If the power delivered was too high, it caused rapid desiccation of the tissue around the active needles, increased the impedance, and thus prevented any further delivery of RF waves into the tissue. Using these first generator models, urologists at times had to find a precarious balance between the appropriate energy level required to continue to drive the development of the lesion and the rise in temperature. If the latter was too rapid because excessive energy had been delivered, it caused a sharp increase in impedance and led to charring of the tissue around the active needles, preventing further tissue ablation. To manually adapt the power, constant monitoring by the urologist of both needle placement and generator keyboards was necessary. The procedure was not completely reproducible and unavoidable variability occurred. Maximum temperatures had to be reached within about 1 min of treatment, and then maintained for at least an additional 3 or 4 min without variation in the impedance itself. This was sometimes difficult to achieve.

In 1997, the ProVu system introduced improved optics with an automatic shield of deployment. With this new catheter, needles and protecting shields could be viewed as they entered the prostatic lobes, a routine with cystoscopic procedure. Reusable handles with disposable cartridges were also introduced along with an 18.5F delivery system. In 2002, a new generation of TUNA catheters and generators, Precision Plus™, was developed. In contrast to the first-generation catheters, thermosensors could now be placed at the tip of the needle to give the maximum temperature at the core of the lesion (Figure 125.2). There was no longer a need to extrapolate the maximum temperature in the lesion itself from readings at the shield. This obviously both standardized and simplified the procedure. Lesion time was 25% faster (3 min) and larger needles (24G) were provided for more consistent heating in all types of tissue.

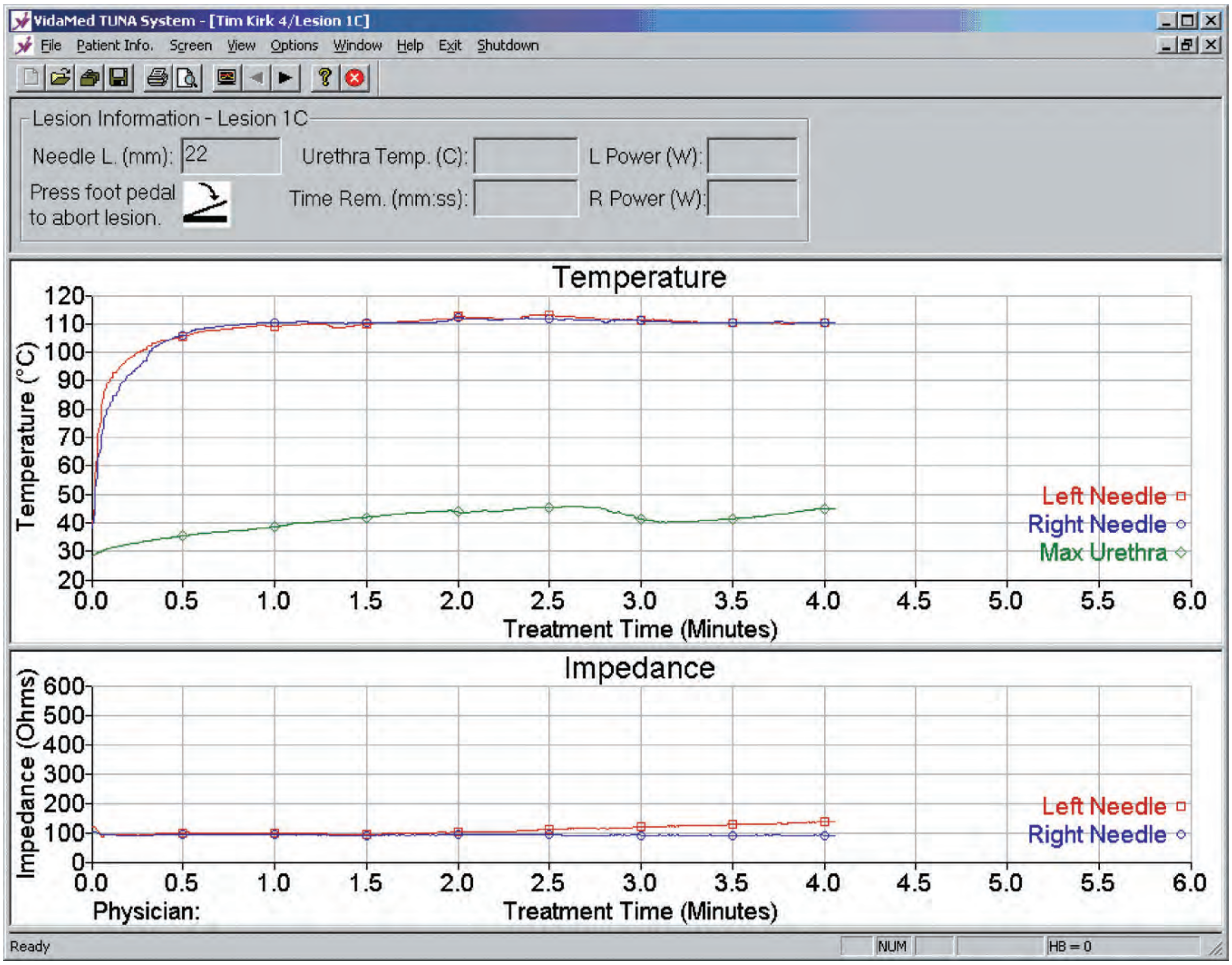
As we had done with the first TUNA system, we analyzed the extent of the thermal lesions induced by 2, 3, and 4 min of treatment using the new TUNA Precision Office system in 10 patients treated with TUNA immediately prior to retropubic prostatectomy for BPH. Histologic sections were stained with NADPH and H&E (Figure 125.3) to analyze thermal damage and necrosis on macroslides (Figure 125.4). All treatments were performed in the right lobe and the left prostatic lobe was left untreated and used as the control. Lesions created with 2 min of treatment (up to 14 × 10 mm) were smaller than those created with 3 and 4 min of treatment [27].

In 2006, the latest technology, the Prostiva RF, was introduced. This generator is fully automated and can deliver energy much more rapidly, creating a lesion in about 2 min 20 s (much faster than the Precision Plus), with a target temperature of 115°C. Integrated disposable hand pieces are another feature of this improved system. Needles can be deployed at a depth of 12, 14, 18, 20, and 22 mm into the prostatic parenchyma as required (Figure 125.5).

The new generators are much lighter (7 lb) and more compact than the originals (Figure 125.6). The set-up is undoubtedly easier and a new user interface with touchscreen controls adds to the user-friendliness of the system. On the hand piece, 6-Hz monitors control urethral and prostatic temperatures, whereas a 5-kHz monitor controls RF power. The 50-MHz controls measure impedance and power. Computerized graphics allow the urologist to view treatment in realtime (Figure 125.7). The rod–lens telescope is compatible with all medical-grade video camera systems and light sources, and can be used with direct vision. The telescope is a rigid optic telescope with a 0°/15° viewing angle and is designed for reuse by autoclave sterilization. The hand piece is single use.

Treatment procedure

The TUNA procedure is performed with the patient in the lithotomy position. The device is inserted via the urethra down to the prostatic area, under fiberoptic vision control, as in any simple cystoscopic procedure. The catheter shaft is rotated in order that the needles face the prostatic lobe to be treated. The catheter is placed in contact with the prostatic urethra, and the needles and shields are deployed. Of note, the operator has to imprint a slight pressure on the lobe before deploying the needles to ensure their penetration without the tip of the catheter being pushed away from the lobe by the resistance on the needles. The needles are deployed at the 10 and 8 o'clock positions in the right lobe, and at the 2 and 4 o'clock positions in the left lobe. The length of the needles and extent of shield deployment are determined by preoperatively by measuring the transverse section of the prostate using transrectal ultrasound. In the Prostiva RF generator, a table indicates optimal needle length according to the prostate's transverse diameter (Figure 125.8). Needles should not be deployed more than 6 mm



VidaMed TUNA System - [Tim Kirk 4/Lesion 1C]

Lesion Information - Lesion 1C

Needle L. (mm): 22

Urethra Temp. (C):

L Power (W):

Press foot pedal to abort lesion.

Time Rem. (mm:ss):

R Power (W):

Physician:

Ready

File
Patient Info.
Screen
View
Options
Window
Help
Exit
Shutdown
Temperature
Temperature (°C)
120
110
100
90
80
70
60
50
40
30
20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
Treatment Time (Minutes)
Left Needle
Right Needle
Max Urethra
Impedance
Impedance (Ohms)
600
500
400
300
200
100
0
Treatment Time (Minutes)
NUM
HB = 0

Figure 125.2 Temperature and impedance measurements (personal experience).

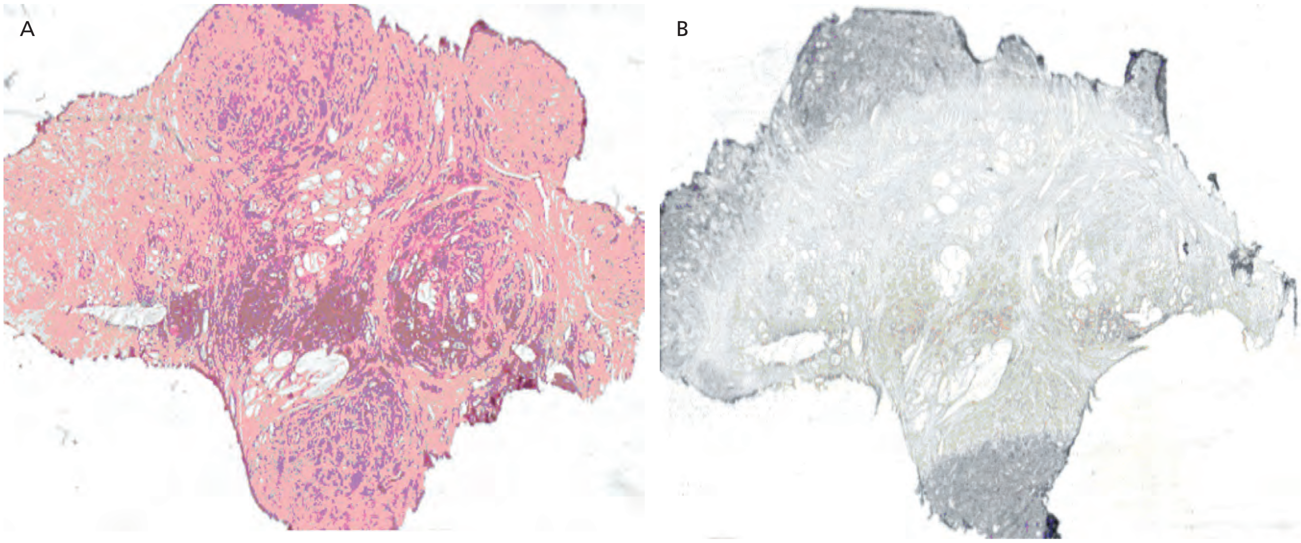


Figure 125.3 (A) H&E staining and (B) NADPH staining. Purple areas shows destructed tissue; white areas show the lesion [25].

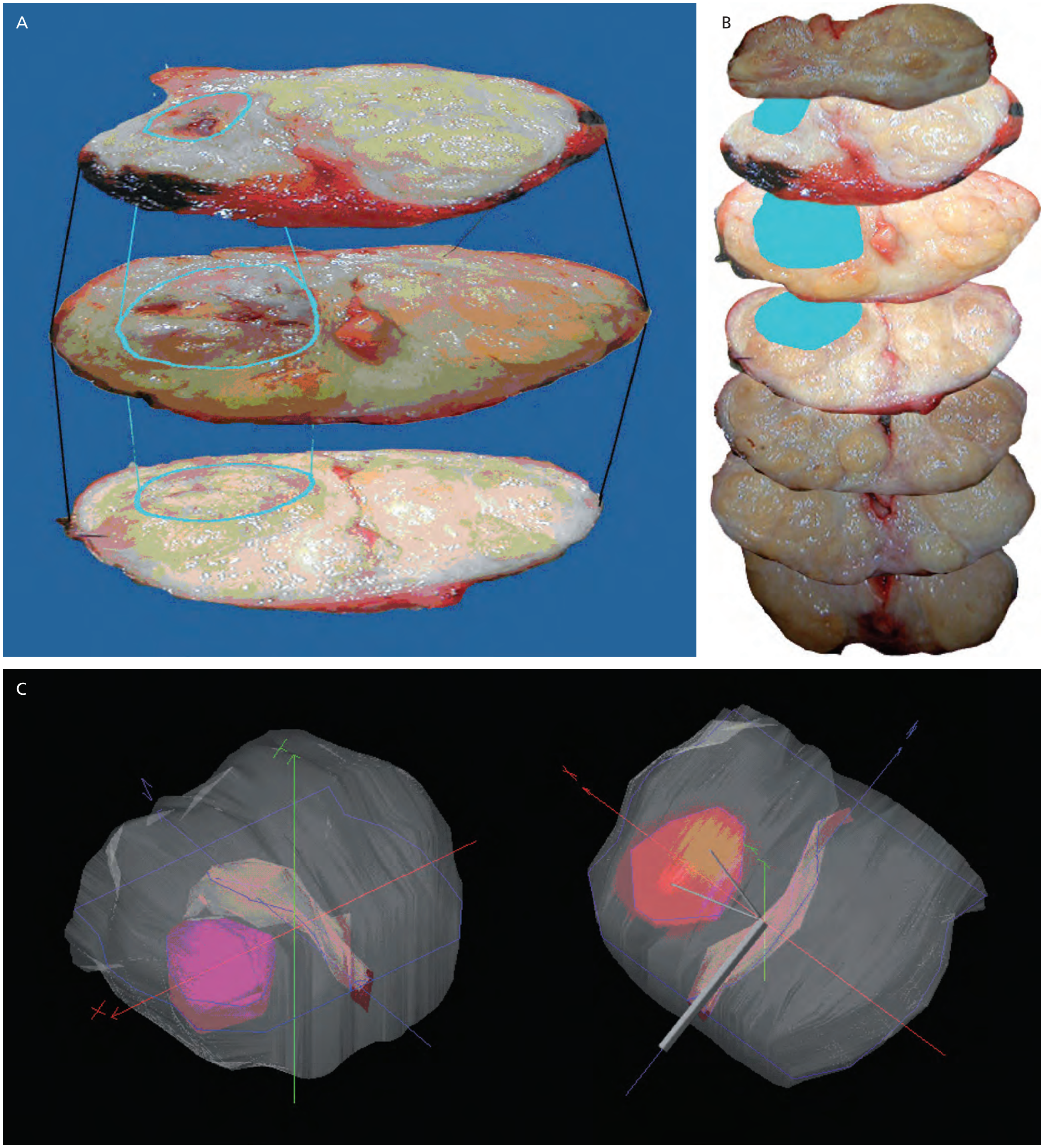


Figure 125.4 (A) Macroslides showing reconstructed lesions and needle path; (B) Macroslides showing reconstructed lesions; (C) Three-dimensional reconstruction of lesion extent [25].

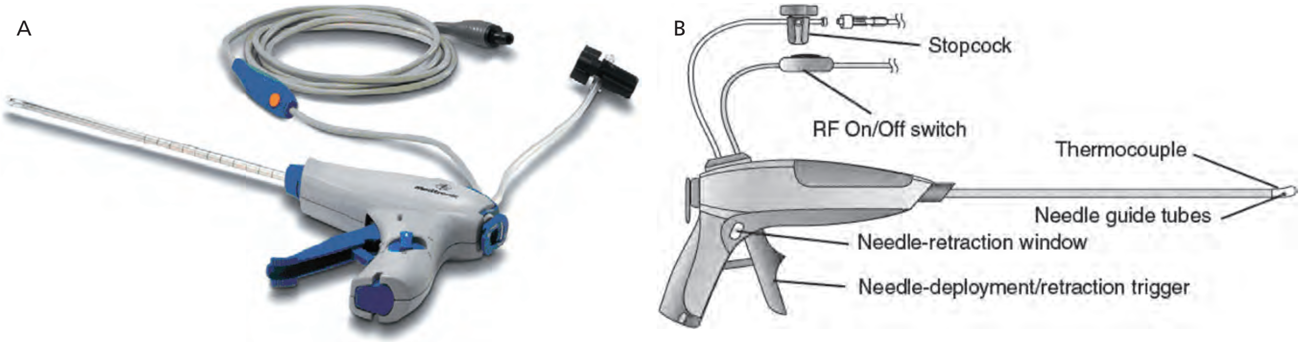


Figure 125.5 (A) Prostiva's latest generation of catheter. (B) Catheter handle, needles and switches (courtesy of Medtronic).

Medtronic
PROSTIVA™

Figure 125.6 Current Prostiva generator (courtesy of Medtronic).

less than half the diameter of the prostate to avoid thermal injury beyond the prostatic capsule, including damage to the neurovascular bundles, although arguably for the lateral lobes of the prostate, this may not be important. Both lateral lobes are treated in two to five planes (depending on the size of the prostate), starting 1 cm from the bladder neck to 1 cm proximal to the verumontanum (Table 125.1). The number of lesions to be created for different prostate sizes and bladder neck–verumontanum lengths is presented in Table 125.2. Treatment recommendations for different median lobe dimensions are given in Table 125.3.

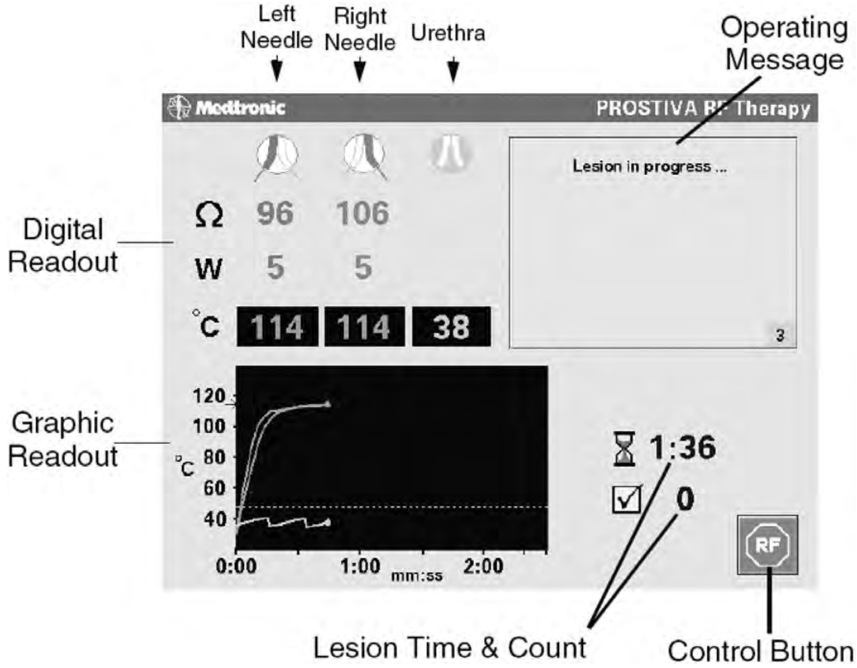
Prostiva generators are equipped with computer-assisted software that automatically adapts the power delivered into the tissue according to the measured impedance. The system can reach temperatures above 110°C and maintain this for the 2.20-min coagulative ablation lesion time.

Anesthesia requirement

There is a wide variation in the anesthetic requirement for TUNA therapy between different institutions and urologists. With experience, the procedure can be conducted under local anesthesia only, which may include intraurethral lidocaine gel, intravesical liquid lidocaine, transrectal periprostatic block, or a combination of these. Supplemental oral or parenteral sedation/narcotics may be used, if required. This was given at the beginning of the TUNA experience.

Regarding local anesthesia, the bladder is first emptied using a catheter, then 40 mL of cold (4°C) injectable liquid lidocaine is injected into the bladder through the same catheter (Table 125.4). Lidocaine gel 20 mL is then instilled into the urethra and the penis clamped for 10–20 min before the procedure. For a periprostatic block, 10 mL of xylocaine 1% is injected under transrectal ultrasonography into the lateral base of the prostate, exactly as is usually does for transrectal prostate biopsies. Nowadays, most procedures are indeed performed very similarly to prostate biopsies. Numerous randomized prospective trials have demonstrated the usefulness of transrectal injection of various anesthetics [28–30]. Issa *et al*. performed a prospective multicenter study of transperineal (rather than transrectal) prostatic block in TUNA in 39 men with symptomatic BPH [31].

In our personal experience, TUNA can be easily performed under local anesthesia with transrectal ultrasound-guided injections starting from the seminal vesicles down to the prostatic apex. The prostate is lifted upwards and a plane below the prostate is very clearly visible as a large hypoechoic zone that penetrates the


Left Needle
Right Needle
Urethra
Operating Message
Medtronic
PROSTIVA RF Therapy
Digital Readout
Ω 96 106
W 5 5
°C 114 114 38
3
Graphic Readout
120
100
°C 80
60
40
0:00
1:00
mm:ss
2:00
1:36
☑ 0
RF
Lesion Time & Count
Control Button

Lesion in progress ...

Figure 125.7 Computerized graphics detailing the transurethral needle ablation readouts (courtesy of Medtronic).

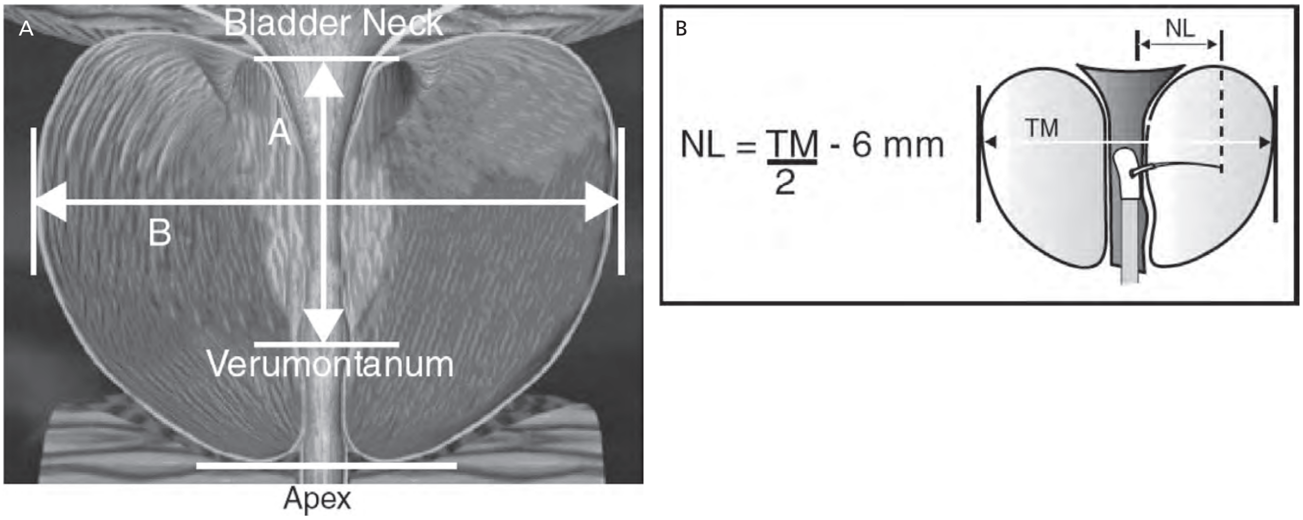

A
Bladder Neck
A
B
Verumontanum
Apex
B
NL
NL = TM/2 - 6 mm
TM

Figure 125.8 (A, B) Calculating needle length (courtesy of Medtronic).

Table 125.1 Treatment planes according to prostate length (courtesy of Medtronic).

Bladder neck–verumontanum length (cm)	Number of treatment planes	Treatment planes
<3	2–3	Proximal and distal
3–4	3–4	Proximal Mid point and distal
4–5	4–5	Mid point Mid point and distal

Table 125.2 Typical needle settings according to transverse diameter of the prostate (courtesy of Medtronic).

Transverse measurement range (mm)	Needle length (mm)
36	12
36–40	12, 14
40–44	14, 16
44–48	16, 18
48–52	18, 20
52–56	20, 22
56–80	22

Table 125.3 Suggested treatment according to median lobe size (courtesy of Medtronic).

Median lobe dimensions (cm)	treatment regions	Treatment locations
<3 cm wide	1	10, 12, 2 o'clock
3 cm wide	2 or more	10, 12, 2 o'clock
3 cm long	1	12 o'clock
>3 cm wide	2	6, 12 o'clock

Table 125.4 Suggested local anesthesia (courtesy of Medtronic).

Step 1: 60 min preprocedure

Oral analgesic 10.0 mg oxycodone with paracetamol/acetaminophen (Percocet)

Oral sedative 10.0 mg diazepam

NSAIDs 50.0 mg rofecoxib (Vioxx)

Antibiotics

Anticholinergics 4.0 mg tolterodine tartrate (Detrol LA)

Step 2: 20 min preprocedure

Place patient in a semi-Fowler's position

Empty bladder with the catheter

Instill 40 of –60 mL cold (4° C) liquid lidocaine 2% injectable vial into the bladder via the catheter

Slowly pull catheter out while continuing to instill the last 10 mL of lidocaine into the urethra
Instill 20 mL of lidocaine gel, clamp the penis

tissue at that level (Mount Everest sign). Local anesthesia (5–7 mL) is given on each side of the prostate (Figure 125.9). The prostatic block has dramatically improved the tolerance of the TUNA procedure. Leocadio *et al.* successfully treated 56 consecutive patients with office-based TUNA using oral rofecoxib (50 mg) and ciprofloxacin (250 mg) before administering 25 mg of hydroxyzine and 50–100 mg of meperidine intramuscularly [32].

Mechanism of action

Histologic examination shows that radiofrequency ablation of the prostate leads to localized, spheroidal, reproducible necrotic lesions up to 4 mm from the needles; neurohistochemical analysis shows severe thermal damage to intraprostatic nerve fibers that extend beyond the area of tissue necrosis, and it has been postulated that this may contribute to clinical improvement.

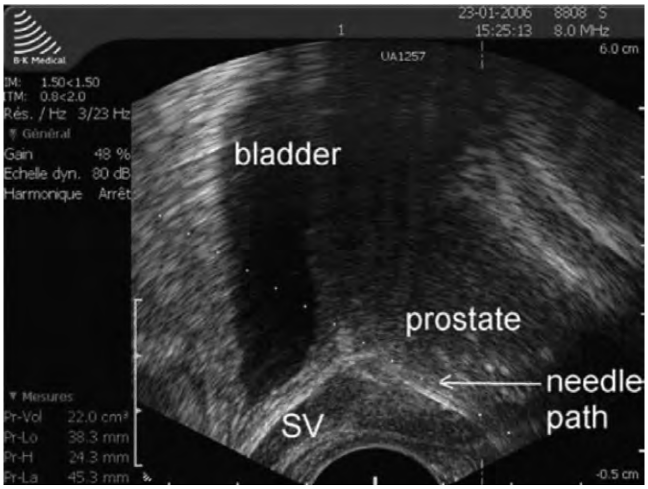


Figure 125.9 Local anesthesia: a needle is introduced through the transurethral ultrasound (TRUS) probe in the plane between the rectum and the prostate up to the seminal vesicles (SV). Anesthetic is injected while withdrawing the needle from the base to the apex of the prostate (with kind permission from Springer Science + Business Media: *World J Urol*, How do I treat and follow my TUNA patients, 24:4, 2006, Sas Barmoshe).

We investigated the mechanism of action of TUNA by analyzing 10 open prostatectomy specimens (BPH) recovered 1-46 days after TUNA. These were stained with H&E and an immunohistochemical technique that used antibodies against S100 proteins and nonspecific enolase as specific nerve markers, and against antiprostate-specific antigen (anti-PSA) and antidesmin for glandular and muscle cells, respectively. We used five BPH specimens as controls. Nerve fibers in the control specimens and untreated prostatic areas predominated in the urethral submucosal layer and stroma surrounding the epithelial nodules, with a quasi absence of nerve endings in the prostatic stroma. The sparsity of nerve endings in the prostate adenoma possibly explains the excellent tolerance of TUNA as an anesthesia-free, minimally invasive treatment, provided the urethral and capsular nerve endings are taken care of with local anesthetics. No staining of any axon or nerve cell was observed in any specimen treated by TUNA, and there was a sharp and clear delineation between treated and untreated areas. Severe thermal damage to intraprostatic nerve fibers caused by TUNA was demonstrated. This study suggested that long-term denervation of alpha-receptors and/or sensory nerves could explain the clinical effects of TUNA of the prostate.

We have also shown using magnetic resonance imaging (MRI) that the first-generation TUNA systems induced large coagulative necrotic lesions of a size in line with that anticipated size from the needle deployment [8].

Huidobro *et al.* analyzed dynamic, gadolinium-enhanced MRIs to characterize the ablative properties of the Prostiva RF device in 10 men with LUTS due to BPH [33]. Gadolinium-enhanced MRI sequences were obtained prior to and 1 week post treatment. New gadolinium defects were seen in all patients following

Prostiva treatments. All lesions coalesced within the prostate. No defects were seen beyond the prostate and the urethra was spared in all patients. The mean volume of necrosis was 7.56 mL, representing a mean of 11.28% of total prostate volume. The standard Prostiva RF protocol produced lesions that coalesced to create larger lesions in the bladder neck and lateral lobes. , The ablative lesions were comparable to those produced with the TUNA Precision Plus device, but were achieved with a shorter burn time [33].

It is clear that the amount of tissue "debulked" is relatively small and that TUNA efficacy cannot scientifically be explained by its mechanical action on the bladder outlet obstruction alone. There is very likely to be a "dynamic" mechanism of action as well, possibly similar to that observed using medical therapy (alpha-blockers). Fine-tuning of our understanding of the mechanisms of action may require additional studies.

Table 125.5 Prostate volumes of patients treated with transurethral needle ablation (TUNA) (courtesy of Medtronic).

	Prostate volume (mL)		
Study	Inclusion criteria	Mean (SD)	Range
Hill *et al.* [36]	20–75		
Zlotta *et al.* [37]	<90	53.8 (17.9)	
Roehrborn *et al.* [24]		36.1 (17.1)	
Kahn *et al.* [38]		48.05	20–185
Murai *et al.* [39]	15–75	38.6 (15.3)	
Minardi *et al.* [40]		57 (15)	
Campo *et al.* [16]	15–75		
Steele and Sleep [26]	<65		
Issa *et al.* [41]		40.5	17–129
Fujumoto *et al.* [42]		43.6 (16.7)	
Sullivan *et al.* [43]	>60		60–99
Zlotta *et al.* [8]		43.1 (22.2)	

Indications

Patients considered for RF ablation meet the following criteria:
- Moderate to severe BPH symptoms without clear indication for surgery;
- Dissatisfied with medication results or side effects, concerned about inconvenience of lifelong medical therapy;
- Concerned about side effects associated with surgery or not appropriate candidates for surgery.

RF ablation is contraindicated in patients with active urinary tract infection; neurogenic, decompensated, or atonic bladder, urethral strictures that prevent insertion of the cartridge sheath; malleable penile implants; bleeding disorders or on anticoagulation medication unless antiplatelet medication has been discontinued for at least 10 days; and presence of any prosthetic device in the region that may interfere with the procedure. In patients with a cardiac pacemaker or implantable defibrillator, there is a potential risk due to the interference between RF frequency and the pacemaker, but we have performed the procedure safely in such patients. The advice/presence of an anesthetist is suggested, as well as the availability of a magnet in the room.

Prostate volume

Prostate lobes of varying sizes and shapes can be treated, including asymmetrical prostates and median lobe (except those that grow into the bladder and collapses across the bladder). Studies analyzing the effect of TUNA on patients with median lobe enlargement report improvements similar to those in the general population with symptomatic BPH [34, 35]. However, prostate glands less than 34 mm or greater than 80 mm in transverse diameter are usually not recommended for treatment. Our personal opinion is that the most suitable prostate sizes are between 20 and 50 cm^3; however, this may be debatable (Table 125.5) [8, 16, 24, 26, 36–43].

Clinical efficacy

Meta-analyses

The short- and long-term effectiveness of TUNA of the prostate for clinical BPH has been published in two systematic review and meta-analyses [44, 45].

Boyle *et al.* extracted data from two randomized trials, two non-randomized observational protocols, and 10 single-arm studies conducted on TUNA, according to a determined protocol [45]. The meta-analysis was based on the change in the mean score at the end of study from that at baseline. The estimation of the effects from the meta-analysis used a multilevel model including random effects for the studies. TUNA was found to halve the mean International Prostatic Symptom Score (IPSS) at 1 year after treatment and, although there was a slight tendency for the IPSS to increase in all arms from year 1 to year 5, this decrease was maintained at 5 years. The maximum urinary flow rate (Qmax) also increased by approximately 70% from baseline to 1 year. Although there was a tendency for Qmax to decline slightly over time, the mean Qmax 5 years after treatment was about 50% over baseline. This meta-analysis concluded that TUNA was an effective and minimally invasive treatment for men with clinical BPH, even when symptoms were severe. It appeared to be an alternative to surgery and an attractive option for men who do not wish to undergo long-term medical therapy, are poor candidates for surgery or are concerned about the side effects of TURP.

A second and larger meta-analysis was reported in Spain by Bouza *et al.* [44]. The authors postulated before embarking on their study that its impact on BPH and role among other currently available therapeutic options were unclear. In order to ascertain the efficacy and safety of TUNA in the treatment of BPH they performed a systematic review of the literature up to January 2005 and a meta-analysis of clinical studies assessing TUNA in symptomatic BPH. Studies of 10 or more patients that contained relevant primary clinical data were critically appraised. Estimates of effect were calculated according to the random-effects model. Two independent reviewers carried out the study selection and data extraction. A third reviewer checked the extracted data and the team resolved any discrepancies. Thirty-five studies (nine comparative, 26 noncomparative) were included that assessed TUNA versus TURP and other minimally invasive techniques. No study comparing the efficacy and safety of TUNA with medical treatment was found in the literature to date.

Although evidence was limited by methodologic issues, the analysis of relevant outcomes indicated that while TUNA significantly improved BPH parameters with respect to baseline, it did not reach the same level of efficacy as TURP in respect to all subjective and objective variables. Further, its efficacy declined in the long term with a rate of secondary treatment significantly higher than for TURP (OR 7.44, 95% CI 2.47–22.43). Conversely, TUNA seemed to be a relatively safe technique and showed a lower rate of complications than TURP (OR 0.14, 95% CI 0.05–0.14), with differences being particularly noteworthy in terms of postoperative bleeding and sexual disorders. Likewise, TUNA had fewer anesthetic requirements and generated a shorter hospital stay than TURP [weighted mean difference (WMD) −1.9 days, 95% CI −2.75 to −1.05]. Available evidence suggested that TUNA is a relatively effective and safe technique in selected patients with symptomatic BPH. The review indicated that there were insufficient data to define with any degree of accuracy the role of TUNA *vis-à-vis* other minimally invasive therapies.

Table 125.6 Improvement in subjective and objective parameters following transurethral needle ablation (TUNA) (courtesy of Medtronic).

		Change from baseline		
Study	Follow-up	IPSS-AUA SI	Qmax (mL/s)	PVR (mL)
Boyle *et al.* [45]	1 year[a]	−12.1	+5.1	NA
Hill *et al.* [36]	5 years[b]	−13.3	+2.6[h]	−31.4[c]
Zlotta *et al.* [37]	5 years[d]	−12.2	+3.5	−58.0
EAU Real-Life Data Registry [46]	1 year	−10.6	+3.0	NA
Savoie *et al.* [47]	2 years	−3.0	+2.0	NA
Bruskewitz *et al.* [15]	1 year[b]	−13.6	+6.3	−27.8[e]
Roehrborn *et al.* [24]	1 year[b]	−11.8	+5.9	−21[f]
Kahn *et al.* [38]	1 year[a]	−11.0	+6.59	+62.0
Murai *et al.* [39]	1 year	NA	+11.2[h]	−31.8[g]
Roehrborn *et al.* [48]	6 months[b]	−13.1	+4.7	NA
Minardi *et al.* [40]	2 years[g]	−12.4	+4.9	−40.9
Campo *et al.* [16]	18 months	−14.1[d]	+5.9[g]	NA
Steele and Sleep [26]	2 years[h]	−12.9	+4.4	−39.2
Fujimoto *et al.* [42]	3 months[b]	−13.0	+3.3	+16.9[h]
Sullivan *et al.* [43]	6 months[a]	−7.79	+4.12	NA

[a] Significance not stated.
[b] $P < .0001$ except where stated.
[c] $P = .0872$.
[d] $P < .001$.
[e] $P = 0.0249$.
[f] $P = 0.029$.
[g] $P < .001$.
[h] $P < 0.05$.
NA, not available; Qmax, maximum urinary flow rate; IPSS, International Prostatic Symptom Score; AUA SI, American Urological Association Symptom Index; PVR, postvoid residual volume.

TUNA leads to a significant improvement in both subjective and objective variables over preintervention values (Table 125.6) [15, 16, 24, 26, 36–40, 42, 43, 45–47]. TUNA reduces the symptom index and quality-of-life score by 50–60% with respect to pretreatment values, an improvement that is maintained across follow-up, though a progressively downward trend is evident after 3 years. With respect to the objective parameters, TUNA leads to improvements which, though significant, amount to an increase of around 30–35% over baseline values. Its effect, albeit to a minor degree, is also demonstrated in terms of improvement in urodynamic parameters [26]. Some authors have suggested the effect of TUNA on objective variables is weaker in the case of prostates larger than 50 g. Others, however, do not observe that size exerts a significant influence on patients' response and suggest that this should not be an exclusion criterion for the use of the system.

In the meta-analysis by Bouza *et al.*, 15 studies [13, 18, 25, 35, 37–39, 42, 48–55] provided data on the need for new interventions following TUNA and, though their individual results varied widely, combined analysis indicated that 237 of 1036 patients treated with TUNA required new treatments, amounting to an overall

Table 125.7 Summary of the characteristics of studies comparing transurethral needle ablation (TUNA) with other therapies (from Bouza *et al*. [44]; BioMed Central Ltd.)

	Bruskewitz *et al.* [15]	Roehrborn *et al.* [48]	Chandrasekar *et al.* [58]	Cimentepe *et al.* [57]	Hill *et al.* [36]	Schatzl *et al.* [59, 60]	Arai *et al.* [56]	Minardi *et al.* [61]
Design	RCT	RCT	RCT	RCT	RCT	Prospective cohort	Prospective cohort	Prospective cohort
Total number of. Patients	121	121	156	59	121	95	204	212
Number of TUNA patients	65	65	76	26	65	15	51	24
Comparator (number of patients)	TURP (56)	TURP (56)	TURP (76)	TURP (33)	TURP (56)	TURP (28) TUVP (17) VLAP (15) HIFU (20)	TURP (65) TUMT (40) ILC (48)	TURP (90) TUVP (13) ILC (71) WIT (13)
Duration of symptoms	>3 months	>3 months	NR	NR	>3 months	NR	NR	NR
Anesthesia	TUNA: local TURP: general	TUNA: local TURP: general	NR	Regional	TUNA: local TURP: general	General/regional	TUNA, ILC: NR TURP: spinal TUMT: local	TUNA–WIT: local TUVP, ILC: spinal TURP: general
Variables assessed	Symptoms, QoL, Qmax, PVR, prostatic size, adverse effects, duration of procedure, hospital stay	Pdet at Qmax, number of Abrams–Griffiths	Symptoms, QoL, Qmax, adverse effects, hospital stay, retreatment	Symptoms, QoL, Qmax, PVR, sexual function, prostatic size, adverse effects, duration of procedure, hospital stay, retreatment	Symptoms, QoL, Qmax, PVR, adverse effects, hospital stay, retreatment	Symptoms, QoL, Qmax, PVR, adverse effects, hospital stay, retreatment	Symptoms, QoL, Qmax, PVR, sexual function, adverse effects	Symptoms, QoL, Qmax, PVR, Pdet at Qmax, prostatic size, adverse effects, duration, retreatment
Follow-up	12 months	6 months	7 years	18 months	5 years	6 weeks/24 months	3 months	24 months
Randomization method specified	Yes	Yes	No	No		NA	NA	NA
Inclusion/exclusion criteria specified	Yes	Yes	No	Yes		Yes	Yes	Yes
Concomitant treatment specified	Yes	Yes	No	Yes		Yes	No	No
Intention-to-treat analysis	Yes	Yes	NR	NR		Yes	NR	NR
Blind/independent evaluation	NR	NR	NR	NR		NR	NR	NR
Losses (number of patients)	TUNA: 9% TURP: 16%	None	NR	None	TUNA: > 72% TURP: > 60%	TUVP (4) VLAP (4) HIFU (4) TUNA (3)	TUNA (9) TURP (10) TUMT (6), ILC (6)	NR

RCT, randomized controlled trial; TURP, transurethral resection of the prostate; TUMT, transurethral microwave thermotherapy; WIT, water-induced thermotherapy; ILC, interstitial laser coagulation; TUVP, transurethral electrovaporization of the prostate; VLAP, visual laser ablation of the prostate; HIFU, transrectal high-intensity focused ultrasound; QoL, quality-of-life score; Qmax, maximum urinary flow rate; PVR, postvoid residual volume, Pdet at Qmax, detrusor pressures at peak flow rate; NR, not reported; NA, not applicable.

retreatment rate of 19.07% (95% CI 18.7–39.7) [44]. These new treatments mainly consisted of surgical measures, namely TURP (150 cases), unspecified surgery (22), second TUNA (7), prostatectomy (6), and transurethral incision of the prostate (1). A total of 41 patients received drug therapy. In 10 cases, the treatment employed was not specified.

Comparative studies

Transurethral needle ablation versus transurethral resection of the prostate

The general and methodologic characteristics of studies comparing TUNA with TURP are shown in Table 125.7 [15, 36, 48, 56–61]. In terms of design, four were non-randomized and five were randomized studies. The total number of patients included in randomized studies was 336 (167 treated with TUNA, 169 with TURP).

Both techniques provide significant improvements in BPH parameters and, initially, the efficacy of TUNA would seem to be equivalent to that of TURP. However, at 12 months, subjective parameters and objective functional measures are both statistically better with TURP.

The combined results of the meta-analysis of Bouza *et al*. indicated that TUNA had a retreatment rate significantly higher than that of TURP: 10% (21 of 206) of patients treated with TUNA versus a mere 1% (3 of 282) of TURP patients [44]. Rosario *et al.* demonstrated a high retreatment rate in their study as well; however, it should be stressed that their study was performed using older versions of catheters and generators [62].

The effects of treatment on sexual function were analyzed in three studies [15, 56, 57] that used different scales. In one randomized clinical trial, 53% of the TURP versus only 13% of the TUNA cohort reported diminution in the volume ejaculated ($P < .001$) [15]. Cimentepe *et al.* observed that 100% of patients treated with TUNA reported no change in sexual function, whereas 61% of patients treated with TURP reported a deterioration [57]. Arai *et al.*, in a non-randomized study, observed a mild–moderate deterioration in erectile function in 26.5% of patients treated with TURP and 20% of patients treated with TUNA, without there being any significant change in the pre- and post-treatment indices of erectile function or libido in either group [56]. In 48.6% and 24% ($P < .001$) of TURP and TUNA patients, respectively, there was loss of ejaculation capacity or an appreciable diminution in the volume ejaculated. There was no mortality associated with either of these procedures, but a total of 67 and 417 adverse effects were reported for the TUNA and TURP groups, respectively. Adverse effects on sexual function were less frequent in the TUNA group. Treatment with TUNA resulted in a significantly lower number of complications than TURP (OR 0.14, 95% CI 0.05–0.41). Overall, TUNA entailed an absolute risk reduction of complications of 19.4% (95% CI 17–22%), with an estimated number needed to treat (NNT) of 5 (95% CI 5–6) to prevent a poor outcome.

Transurethral needle ablation versus other modalities

Only four studies have included comparison of TUNA with other minimally invasive techniques, such as: transurethral microwave thermotherapy (TUMT), water-induced thermotherapy (WIT), interstitial laser coagulation (ILC), transurethral electrovaporization (TUVP), visual laser ablation (VLAP), and transrectal high-intensity focused ultrasound (HIFU).

In a comparison of TUNA versus TUMT, at assessment at 3 months, TUNA-related improvements were significantly superior to those of TUMT in terms of symptom index, quality-of-life score, Qmax and postvoid residual volume (PVR); in addition, there was a trend, albeit nonsignificant, towards a lower number of erectile dysfunctions [63].

Likewise, TUNA seemed to have a significantly better effect than WIT on the objective variables analyzed in the study by Minardi *et al.* [61]. The results *vis-à-vis* ILC proved more difficult to analyze, as each techniques seemed somewhat more effective than the other, depending on the point in time at which they were evaluated. However, adverse effects tended to be more frequent in the group treated with ILC, particularly irritative symptoms, postoperative hematuria, and reduction in seminal volume.

Analysis of the studies comparing TUNA with TVP [59–61] indicated that TVP achieved improvements significantly superior to TUNA in both subjective and objective variables, but this was accompanied by a higher incidence of adverse effects.

Schatzl *et al.*'s results based on 30 patients indicated that, while both VLAP and TUNA led to similar improvements in symptom index, but VLAP had a significantly superior effect on objective variables [59, 60]. Furthermore, there seemed to be fewer adverse effects with VLAP.

Notable differences between TUNA and HIFU were not in evidence in the analysis of the 35 subjects in whom these techniques were compared [59, 60].

Long-term follow-up

Hill *et al.* reported on results of a prospective, randomized, multicenter clinical trial of TUNA versus TURP for the treatment of symptomatic BPH with 5-year follow-up (Table 125.8) [36]. A total of 121 men aged 50 years or older with LUTS secondary to BPH of minimum duration of 3 months were enrolled at seven medical

Table 125.8 Comparative long-term efficacy of transurethral needle ablation (TUNA) and transurethral resection of the prostate (TURP) [36] (courtesy of Medtronic).

	TUNA		TURP	
Parameter	Baseline	5 years	Baseline	5 years
IPSS	24.0 (0.8)	10.7 (1.4)^{a}	24.1 (0.8)	10.8 (1.6)^{a}
QoL score	11.8 (0.5)	3.8 (0.7)^{a}	12.6 (0.5)	4.0 (0.8)^{a}

^{a}*P* < .0001 compared with baseline.
IPSS, International Prostatic Symptom Score; QoL, quality of life.

Table 125.9 Long-term efficacy of transurethral needle ablation (TUNA) [45] (courtesy of Medtronic).

	Mean ± SD	
Parameter	Baseline	After TUNA® Endpoint analysis (% change)
Total IPSS (n = 296)	20.8 ± 5.6	10.2 ± 6.0 (49%)*
IPS-QoL (n = 305)	4.1 ± 1.1	1.8 ± 1.2 (54%)*
Qmax (mL/s; n = 290)	10.5 ± 14.5	13.5 ± 7.4 (69%)*
IIEF-5 (n = 218)	17.0 ± 6.4	17.5 ± 6.0 (8%)
Endpoint: after mean follow-up of 26.8 months		**P* < .0001

IPSS, International Prostatic Symptom Score; QoL, quality of life, IIEF-5, International Index of Erectile Function – 5.

centers across the USA. Improvement from baseline for TUNA and TURP retained statistical significance at each interval for IPSS, quality of life, and Qmax. PVR was statistically significant at all time points for TURP and at year 5 for TUNA. The TURP group reported 41% retrograde ejaculation, while the TUNA group reported none. The incidence of erectile dysfunction, incontinence, and stricture formation was also greater in TURP than in TUNA cases, with significantly fewer adverse events for TUNA than for TURP.

Zlotta *et al.* reported on the 5-year follow-up of 188 consecutive patients with symptomatic BPH treated with TUNA in three different centers in Belgium, Greece, and Norway [37]. All patients were treated using the TUNA II or TUNA III catheters under local anesthesia only, without general or spinal anesthesia. Baseline and 5-year follow-up evaluation included Qmax, IPSS, and PVR. The number of patients requiring additional medical or surgical treatment was recorded. At a mean follow-up of 63 months, mean Qmax increased from 8.6 mL/s to 12.1 mL/s (*P* < .01, t-test), and IPSS and PVR decreased from 20.9 and 179 mL to 8.7 and 122 mL, respectively (both *P* < .001, t-test). The percentage of patients who improved by at least 50% on Qmax or IPSS was 24% and 78%, respectively. Mean prostate volume and PSA levels did not change significantly (53.9 mL vs 53.8 mL and 3.3 vs 3.6 ng/mL, respectively, at 5 years). Two patients died of unrelated comorbidities and 10 were lost to follow-up. Medical treatment was given to 12 patients (6.4%), a second TUNA was performed in seven patients (3.7%), and surgery was indicated in 22 of 186 (11.1%). Overall, 41 of 176 patients (188 at the start, two deaths, and 10 lost to follow-up) (23.3%) required additional treatment at 5-year follow-up. These authors concluded that TUNA provides good long-term clinical improvement at 5-year follow-up. More than 75% of the patients did not need additional treatment for BPH in the long run.

A recent European Association of Urology Real-Life Data Registry analysis of TUNA in over 500 men with LUTS/BPH aimed to provide information from reallife practice on long-term clinical outcome and economics of TUNA treatment for LUTS/BPH with the new Precision Plus and Prostiva RF systems [46]. The registry was set up by the EAU Clinical Research Office in November 2003 to collect follow-up data on 500 treated patients with a minimum of 5 years of follow-up. Enrolment was completed in July 2007. By early September 2009, 526 patients (mean age 66 years) had undergone TUNA at 20 centers in nine European countries. Mean prostate size at baseline was 43 g. Before enrolment, 13% of patients had been in acute urinary retention (AUR), 64% had received pharmacologic treatment (58% α-adrenoceptor antagonists), and 2.7% had undergone minimally invasive therapy. The mean procedure time was 31 min; 99% of patients were satisfied or very satisfied with the comfort during the procedure. Mean follow-up was 21.8 months, with 144 patients discontinuing mainly due to study completion (n = 20) or therapy failure [n = 91 (17%), including 53 patients requiring pharmacologic LUTS/BPH therapy and 30 requiring TURP]. Six-month, 1-year, 2-year, and 3-year follow-up data were available for 386, 308, 210, and 110 patients, respectively. In the 308 patients with follow-up data for at least 1 year, the mean follow-up was 26.8 months and the results for these patients are presented in Table 125.9. Eight-six complications [mainly AUR (41), gross hematuria (9), voiding symptoms (5) and infection (4)] occurred in 68 patients (22%); most complications [70 (81%)] resolved at analysis. AUR had resolved in 34 patients (83%) and required hospitalization in four patients. Retreatment rates, improvements in Qmax and symptom scores were very much in line with, if not slightly better than, with those previously published for the 5-year follow-up of 188

Table 125.10 Noncomparative studies of the safety of transurethral needle ablation (TUNA) (from Bouza *et al.* [44]; BioMed Central Ltd.).

Adverse effect	Number of events	Percentage of total patients
Hematuria:		
Mild	337	28
Moderate	85	7
Transitory unspecified severity	25	2
Severe	16	1
Transitory urinary retention	279	23
Dysuria	167	14
Irritative symptoms	117	10
Urinary tract infection	43	4
Pain during procedure:		
Moderate	11	0.9
Intense	4	0.3
Postoperative perineal pain	13	1
Epidydimo-orchitis	11	0.9
Mild–moderate burning sensation	10	0.8
High fever	8	0.7
Treatment halted due to intolerance to procedure	6	0.5
Urethral stenosis	6	0.5
Erectile dysfunction	4	0.3
Hemospermia	4	0.3
Retrograde ejaculation	3	0.2%
Loss of ejaculation	1	0.08
Prostatism	2	0.2
Complex bladder dysfunction	1	0.08
Damage to the mucosa	1	0.08
Deep vein thrombosis	1	0.8

patients treated with TUNA in three different European centers [37].

Transurethral needle ablation for patients in acute urinary retention

TUNA is an attractive treatment option in those patients who are a poor surgical risk. Zlotta *et al.* have shown TUNA to be a highly effective treatment for relieving AUR due to benign prostatic enlargement (BPE), with almost 80% of patients able to resume voiding spontaneously 2–27 days post-TUNA [55]. Similarly, Harewood *et al.* studied 10 patients with urinary retention. After the procedure, nine patients were able to void at a median time of 3 days [18].

Table 125.11 Catheterization post transurethral needle ablation (courtesy of Medtronic).

Study	Number of patients (%)	Mean catheterization time
Bruskewitz *et al.* [15]	26 (40)	24–48 h
Roehrborn *et al.* [24]	53 (40.8)	3.1 days
Kahn *et al.* [38]	45 (100)	1–5 days
Murai *et al.* [39]	93 (100)	24 h
	30 (32.2)	7 days
	1 (1)	>7 days
Minardi *et al.* [40]	24 (100)	2 weeks
Campo *et al.* [16]	16 (13)	48 h
Steele and Sleep [26]	8 (17)	1–9 days
Fujimoto *et al.* [42]	41 (100)	Up to 2 days
Sullivan *et al.* [43]	3 (30)	Within 3 days

Adverse effects

The description of adverse effects after TUNA is somewhat heterogeneous. Table 125.10 lists the adverse effects identified in the individual studies [44]. The most frequent adverse effect was hematuria, which in most cases took the form of mild bleeding. Retention occurred in 23% of patients but was usually transient, lasting only a couple of days. Dysuria, of lesser or greater intensity, irritative symptoms, which were usually transitory but were not clearly described, and urinary tract infections were other common adverse effects. Extremely few adverse effects with regard to sexual function have been described. Roehrborn *et al.* reported that 22% of patients analyzed reported pain and discomfort [24], and Daehlin *et al.* observed that 42% of their patients presented with moderate and 4% with major malaise [50].

Catheterization requirements post transurethral needle ablation

Studies reporting catheterization time post TUNA are summarized in Table 125.11 [15, 16, 24, 26, 38–40, 42, 43]. Most report catheterization times of less than 1 week.

Cost

The 24-month total procedural cost including expenditures for initial treatment, follow-up care, adverse events, and procedural retreatment after TUNA has been estimated at $6179 [9]. An analysis of 2008 Medicare physician reimbursement for TUNA shows approximate values of $582.43 and $2891.72 for the facility and nonfacility settings, respectively. In practice, however, the procedure is generally performed in the office site of service by most physicians.

Transurethral needle ablation versus other instrumental therapies

The cost-effectiveness of TUNA was demonstrated in a 2001 study by Naslund *et al.* comparing TUNA, TURP, and TUMT [35]. The cost of each procedure was estimated from Medicare reimbursement for 2001 (Table 125.12) and the improvements in IPSS and Qmax at 4 years were used as the effectiveness outcomes. The cost-effectiveness of the different treatment options was calculated in dollars per unit IPSS improvement and dollars per mL/s improvement in Qmax. The study concluded that TUNA is the most cost-effective of the three options in improving symptoms of BPH (IPSS), and TUNA is more cost-effective than TUMT but less cost-effective than TURP in improving Qmax (Table 125.13). Another study by Rosario *et al*. suggests that the high retreatment rate associated with TUNA renders it relatively expensive when viewed as a long-term alternative to TURP for the management of LUTS associated with BPH [62]. They estimated that the additional cost during a 10-year follow-up was $1377. It should be noted that although this may be the case, TUNA was performed using older versions of catheters and generators. However, several features of TUNA make it an attractive treatment option from an economic point of view: Unlike TURP, TUNA can be conducted on an outpatient basis, reducing the cost of hospitalization. Hospital costs are further reduced due to low morbidity, lack of need for bladder irrigation, and low incidence of complications associated with TUNA. The fact that TUNA can be performed under local anesthesia translates into further (considerable) cost savings. The better safety profile of TUNA compared with TURP is of further value to patients, particularly the lack of sexual side effects following treatment with TUNA.

Table 125.12 Comparative costs of transurethral needle ablation (TUNA), transurethral microwave thermotherapy (TUMT), and transurethral resection of the prostate (TURP) (courtesy of Medtronic).

Therapy	Cost of procedure (US$)
TUNA	2455
TUMT	2768
TURP	4500

Table 125.13 Comparative cost-effectiveness of transurethral needle ablation (TUNA), transurethral microwave thermotherapy (TUMT), and transurethral resection of the prostate (TURP) (the most cost-effective option is highlighted) (courtesy of Medtronic).

	Cost-effectiveness measure	
Therapy	Cost per unit IPSS improvement (US$)	Cost per mL/s Qmax improvement ($US)
TUNA	**49.10**	49.10
TUMT	55.34	79.12
TURP	64.30	**44.50**

IPSS, International Prostatic Symptom Score, Qmax, maximum urinary flow rate.

Patients treated with TUNA are able to return to their normal activities (including work) much quicker after the procedure than patients treated with TURP. A study by Sullivan *et al.* indicated that patients can be back to full activity within 72 h of TUNA [43].

Transurethral needle ablation versus medical management

In recent years, combination medical therapy has been introduced as a treatment option for BPH patients. The Medical Therapy of Prostate Symptoms (MTOPS) trial illustrated the benefits of combination medical management using an alpha-blocker and a 5α-reductase inhibitor in some men with BPH.

The results of this model suggest that the TUNA procedure compares favorably with combination therapy on a cost basis. From the payer's perspective, the break-even point between TUNA and combination medical management occurs after approximately 2 years 7 months. Monotherapy with tamsulosin remains less costly than TUNA for 5 years in this model. Monotherapy with finasteride is roughly equivalent in cost to the TUNA procedure over a treatment period of 5 years. When the cost of the mixed scenario medication model is compared with the cost of TUNA, the break-even point from the payer's perspective occurs after approximately 4 years of treatment (Figure 125.10) [63].

Conclusions

There is little doubt and argument about the fact that TUNA has gained its place in the urologist armamentarium for BPH. All major guidelines in the management of LUTS in patients with benign prostatic enlargement include TUNA of the prostate as a valuable treatment option in symptomatic patients with a low-to-moderate degree of bladder outlet obstruction, patients at high risk for surgery, and patients who wish to avoid surgery or regional/general anesthesia.

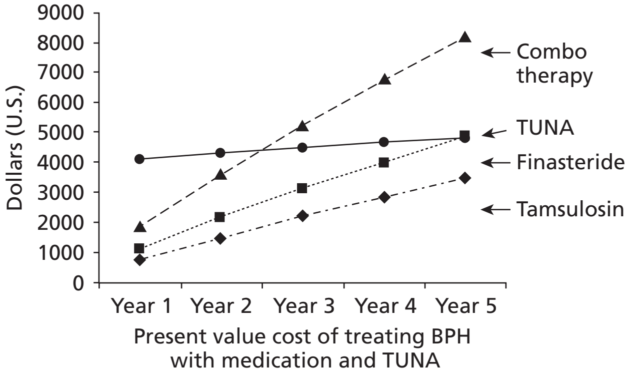


Figure 125.10 Present value cost of treating benign prostatic hyperplasia with medication and with transurethral needle ablation (TUNA) (reprinted from Naslund *et al*. [63], with permission from Elsevier).

The constant evolution in technique and equipment has made the procedure more rapid and more urologist and patient friendly. TUNA is usually performed in an office and under local anesthesia only.

Currently available evidence demonstrates a clinically relevant improvement of subjective (LUTS, quality of life) and objective parameters (Qmax). Impact on voiding dynamics, including detrusor pressure at maximum flow, as well as on prostate volume, remains marginal though, and a scientifically sound and unequivocal explanation for the TUNA mechanism of action remains to be elucidated. A likely permanent denervation from the extensive tissue necrosis is a possible explanation for TUNA efficacy.

TUNA bridges the gap between medical management and surgery. So far, most randomized studies have compared TUNA with TURP, but the indications and ideal candidates for these two procedures only partially overlap. As the indications for surgery and number of surgical procedures for BPH are rapidly decreasing, it seems inappropriate to try to place TUNA as an alternative for patients with clear indications for surgery. The large majority of patients with symptomatic BPH do not have clear indications for surgery, but are rather simply eager to see their symptoms resolved and their quality of life improved, without taking any medication (or without the burden of daily pills). An interesting future study would be to compare TUNA with medical therapy both in terms of outcome and cost-effectiveness.

Longer follow-up is still required to assess the very long-term efficacy of TUNA, but most data with 5 year follow-up, including a recent large-scale European study on 500 patients, suggest that outcomes are maintained long term, with at least 75% of patients not requiring additional therapies, although isolated reports have been less optimistic [46].

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CHAPTER 126

Prostate Laser Vaporization Using the 980-nm Laser System

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Introduction

For numerous decades, transurethral resection of the prostate (TURP) has been considered as the gold standard treatment for benign prostatic hyperplasia (BPH). Although TURP significantly improves lower urinary tract symptoms (LUTS), complications associated with this procedure, such as TURP syndrome and operative bleeding requiring blood transfusion, are still reported in up to 20% of operative cases [1, 2]. Consequently, alternative minimally invasive modalities have been developed. The 980-nm diode laser is one of these new treatment options. This laser wavelength is absorbed by both water and hemoglobin, thus combining high vaporization capacities and excellent coagulation properties [3]. This fact has been confirmed in more than one *ex vivo* porcine kidney model [4, 5]. Early results with the 980-nm wavelength *in vivo* are under investigation.

Herein, we describe the 980-nm laser: its unique wavelength characteristics, procedural techniques, results, limitations and complications, and potential future directions of this exciting new technology.

First, from a physical standpoint, the diode laser emits a wavelength of 980 nm, which is effectively absorbed by both water and hemoglobin. This is significantly different from the 532-nm wavelength, which is absorbed extremely well by hemoglobin, but poorly by water. It also differs from the 2100-nm laser in which the energy is highly absorbed by water, but insignificantly by hemoglobin. Thus, at 980 nm, prostatic tissue, which is constituted by significant amounts of both water and hemoglobin, can be effectively vaporized. Also, scar tissue and previously radiated prostate tissue, both of which contain significantly lower amounts of hemoglobin, may also be vaporized.

Second, the laser energy at 980 nm also has slightly greater penetration of energy into the prostate gland, producing outstanding hemostasis.

Lastly, the irritative symptoms, which commonly occur post prostatic laser vaporization, have been very manageable. One of the concerns in the BPH community has been that if the energy is driven deeper into the prostatic tissue, these irritative symptoms will be increased in both severity and duration. To date, this has not been noted. However, the complication of delayed prostatic chip formation and slough has been noted, but with a change in operative technique, appears to have lessened in frequency.

This technology has also progressed in the last 2 years in both its power capabilities and its fiber-tip design. The early laser boxes generated significantly less power, and it was not until the 120-W device was produced that prostatic vaporization became a potentially efficient form of vaporization. Currently at the Cleveland Clinic Foundation (CCF), we are evaluating the 180-W device, which, in a limited number of cases, appears to be significantly more efficient at vaporization, thus shortening operative times. The fiber-tip designs are also under continued assessment and evaluation, and different tip designs may be more or less efficient and desired depending on certain prostatic characteristics. Presently, fiber tips of side-fire, end-fire, and Twister fiber™ are

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available and under evaluation. Different fibers, with different characteristics, may have physical advantages in a variety of prostatic conditions, such as extensive middle lobe intravesical extension or bilobar hypertrophy with kissing lobes. This aspect of the technology remains under intensive investigation.

We continue to look at a variety of technologies for post brachytherapy and post cryotherapy urinary retention, for which no good therapeutic option currently exists. Again the 980-nm wavelength is currently under evaluation for these.

Preoperative evaluation

Proper patient selection prior to performing any BPH procedure remains of paramount importance. Every patient should be evaluated with a focused history and physical exam, including a digital rectal exam. An assessment of American Urological Association (AUA) symptom score and quality-of-life score, urinalysis, free urinary flow rate, postvoid residual volume (PVR), prostate-specific antigen (PSA), when appropriate, and voiding diary should also be performed.

Urodynamics have a utility in assessing bladder function and confirming bladder outlet obstruction in men with LUTS. However, pressure flow studies in the management of LUTS and BPH are controversial and are currently not recommended for routine use. We currently recommend the use of these studies for patients who demonstrate repeated elevations in PVR levels or have a known or likely component of a neurogenic bladder.

Transrectal ultrasound can confirm prostate size and prostate anatomy for invasive therapy, and assess the presence of any intravesical component and size of the middle lobe, and the presence of prostate cancer, if indicated by the PSA, in concert with a prostate biopsy.

Endoscopic evaluation of the lower urinary tract is not recommended in an otherwise healthy male with an initial evaluation consistent with bladder outlet obstruction (BOO), unless the treatment alternatives being contemplated, such as 980-nm prostate laser vaporization, depend on the anatomic configuration of the prostate, or if hematuria is present [6].

Patients with ongoing treatment with anticoagulants, such as Aspirin, clopidogrel, and coumadin, may be treated. Whenever possible, we prefer to remove these anticoagulants for 5–7 days. However, treatment with the 980-nm laser, because of its excellent hemostatic properties, can still be performed if these agents are not able to be suspended for reasons of the patient's health.

Wavelength and fiber characteristics

The 980-nm diode laser has been recently introduced at a power between 120 and 200 W. As mentioned, the energy emitted at this wavelength is highly absorbed by both water and hemoglobin, thus combining the highly efficient tissue ablative properties with excellent hemostasis. However, one significant energy question remains up for debate. Does the increased depth of penetration of the 980 nm laser energy into tissue change its effect on clinical symptoms in humans, both in the short and long term? Conflicting results have been obtained in similar experimental animal studies. For example, *ex vivo* investigations on human cadaver prostates revealed a 2.09-mm coagulation zone for the 80 W KTP 532-nm laser, while the 980-nm diode laser showed a coagulation zone up to 3.5 times larger at 7.10 mm [5]. However, Wendt-Nordahl *et al*. reported a thinner coagulation zone (290.1 vs 666.9 µm, $P < .05$) and faster ablation rate (7.24 vs 3.99 g/10 min, $P < 0.05$) for the diode 980-nm laser at 120 W compared to KTP at 80 W in the isolated porcine kidney model [3]. Also, KTP at the 532-nm wavelength is only absorbed by hemoglobin, so the data extracted from a human cadaver prostate model, which is devoid of circulation, may be somewhat controversial. Thus, the clinical significance of the difference in depth of penetration remains controversial.

There currently are numerous different types of 980-nm fibers approved for human use. Side-fire fibers remain the most common form, however, both end-fire fibers and Twister fibers are increasing in popularity.

Anesthesia

While the vast majority of prostate laser vaporization using the 980-nm diode laser is performed in an ambulatory surgery or operative setting, there are anecdotal, nonpeer reviewed reports of these procedures being done in an office setting. This should be the case only in patients with small volume prostates and who are highly motivated to have the procedure performed in the office setting. Physicians have used their own discretion in choosing the office-based analgesia from among:

- Preoperative medications: antianxiolytics, anticholinergics;
- Perioperative medications: intravesical chilled lidocaine/marcaine solution, intraurethral lidocaine, anticholinergics;
- Postoperative medications: alpha-blockers, nonsteroidal anti-inflammatory drugs (NSAIDs).

Also available are local anesthetic blocks, prostate blocks, and pudendal nerve blocks.

Office-based analgesia generally does not include intravenous sedation, but if applied, there should be monitored anesthetic support.

Most commonly, these procedures are done under a spinal or general anesthetic. Intubation is often not necessary, but this decision should be made in conjunction with the anesthetic team.

Procedure

While a variety of techniques have been reported in the literature, the technique described is the one we have found to be the easiest to learn and to teach to residents. The patient is placed in the dorsal lithotomy position and is sterilely prepped and draped. Preoperative antibiotics are administered. A continuous flow cystoscope with a 30º lens is carefully passed through the urethra into the bladder. We personally prefer a short beaked 23F cystoscope, as this reduces urethral trauma and allows the prostate to fall into the urethral lumen, facilitating vaporization. Normal saline is used for the irrigant. The visualization is adequate with saline and this will prevent hyponatremia in the rare event of a prostatic or bladder perforation. The laser fiber is extended just outside the field of view with careful attention to ensure that all markers on the laser fiber are visualized at all times, so that the fiber is not retracted into the scope and therefore avoiding potential cystoscope or lens damage.

The fiber is then placed in a near contact position. This will allow efficient vaporization of tissue, but preserve the integrity of the fiber tip, allowing longer vaporization. Excellent saline flow and visualization is essential for the ease of this procedure and thus, we begin the procedure by vaporizing the prostatic intravesical extension and circumferentially around the bladder neck. Any small bleeding vessels are immediately cauterized by revaporizing the bleeding area with the laser energy. Moving the laser fiber a little further away from the tissue will often help to control these bleeding points. Once the bladder neck has been opened, a wide groove is created from the 5 and 7 o’clock positions at the bladder neck to the level lateral to the verumontanum. The lateral lobes, ceiling, and floor of the prostate are then completely vaporized. Hemostasis is maintained. Once the procedure is completed, the scope is removed, and a 22F Coude catheter is placed. The patient is sent home on the same day, usually 2–4 h postoperatively, and if the urine is clear, the catheter is removed on the morning of postoperative day 1.

Results

There currently are limited results published in peer-reviewed journals and only short-term follow-up of these patients is available. Ruszat *et al*. reported that the 980-nm laser (Limmer Laser, Berlin, Germany; 132 W, side-fire fiber) was safe and effective in treating prostatic tissue [7]. Fifty-five men with a mean age of 72.3 years and an average prostate size 64.7 g were evaluated at baseline and 6 months postoperatively. Symptom score improved from 18.7 to 4.5, quality-of-life score improved from 3.2 to 0.8, maximum flow improved from 10.7 to 15.8 mL/s, PVR improved from 180 to 26 mL, and PSA levels dropped from 4.3 to 1.8 ng/mL. No significant hematuria was noted intraoperatively or postoperatively.

Erol *et al*. published their prospective series of 47 men treated with the 980-nm laser (Biolitec AG, Jena, Germany, 132 W, side-fire fiber) [8]. Their mean age was 65.4 years and average prostate size 51 g. Patients were evaluated at baseline and 6 months postoperatively. Symptom scores improved from 21.93 to 9.87, quality-of-life score improved from 4.19 to 2.15, maximum flow rate improved from 8.87 to 18.27 mL/s, PVR improved from 115 to 48 mL, and PSA levels dropped from 2.54 to 1.77 ng/mL. Once again, no significant intraoperative bleeding was encountered.

Lastly, Chen *et al*. recently reported their results on 55 patients treated with the 980-nm laser (Limmer Laser, 200 W, side-fire fiber) [9]. The average patient age was 72.7 years and mean prostate size 66.3 g. Patients were evaluated at baseline and 6 months postoperatively. Symptom score improved from 20.1 to 4.9, quality-of-life score improved from 5.1 to 2.2, maximum flow rate increased from 5.5 to 19.2 mL/s, PVR decreased from 173 to 21 mL, and PSA dropped from 5.1 to 2.1. No intraoperative or postoperative bleeding was reported.

Complications

All is not perfect, however, with this procedure. Numerous bothersome complications were reported in all studies, some of which required secondary procedures. Ruszat *et al.* reported immediate complications of dysuria in 24%, and transient urge incontinence in 7% of patients [7]. During follow-up there was a concerning bladder neck contraction rate of 15% leading to bladder neck incisions in all patients. An additional 18% of patients complained of persistent or recurring obstructive voiding symptoms. These patients thus had an indication for conventional TURP.

In contrast to these results, Erol *et al.* reported no secondary surgical procedures in their series, but did report a retrograde ejaculation rate of 31%, irritative symptom rate of 23%, and a low percentage of temporary urinary retention or incontinence [8].

Chen *et al.* presented a complication profile of transient urge incontinence in 14.5%, sloughed tissue in 14.5%, recatheterization in 10.9%, and reoperation in 7.3% [9].

Special circumstances

At the CCF, we have assessed at the 980-nm laser for the treatment of men post brachytherapy who developed urinary retention. In this group, we also have found that a significant number of repeat procedures need to be performed secondary to the development of bladder neck contractures or clinically significant sloughed tissue obstruction. Discussion of these potential complications should be mandatory in this complicated patient group.

Conclusions

The 980-nm laser is a viable option in the treatment of BPH. This technology vaporizes tissue efficiently, has excellent hemostasis, and is as well tolerated perioperatively from the symptoms of urinary urgency and frequency as any other vaporization device. Its drawback may be the delayed slough of prostatic tissue as a result of the deeper penetration of energy into prostatic tissue.

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CHAPTER 127

Holmium Laser Therapy of the Prostate

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Introduction

Transurethral resection of the prostate (TURP) has been the reference standard for the treatment of benign prostatic hyperplasia (BPH); however, TURP has an important mortality rate of 0.2–2.5%, immediate postoperative morbidity rate of 13–24%, including bleeding requiring blood transfusion (0.4–6.4%) and TUR syndrome (0.8–2%), and a retreatment rate of 2.3–4.3% within 12 months [1, 2]. This perioperative morbidity of TURP has been the driving force behind the development of several minimally invasive treatments of symptomatic BPH. Laser prostatectomy was first introduced in 1986 and gained popularity after the introduction of the side-firing fiber [3].

The ongoing refinements of laser technology over the past decade hold great promise and have resulted in effective laser applications in the surgical treatment of symptomatic BPH. Laser therapy provides several advantages over standard TURP, including the absence or minimization of complications, such as hyponatremia (TUR syndrome), bleeding, hospitalization, catheter time, and bladder irrigation, with no prostate size limitation. The use of normal saline with laser surgery eliminates the risk of TUR syndrome. The unique hemostatic properties of lasers result in almost bloodless removal of prostatic adenoma, significantly less morbidity and mortality compared to TURP, and a decrease need for blood transfusion and bladder irrigation [4].

Many efforts have been made to identify alternative surgical techniques providing comparable functional results to TURP, but with less morbidity and higher perioperative safety [5]. However, the most frustrating aspect about the use of minimally invasive techniques is the high rate of recurrence and the need for retreatment over time [6].

The holmium (Ho) laser has been associated with strong clinical evidence for its effectiveness in many applications in urology, such as incision of ureteral stricture, lithotripsy of urinary calculi, ablating superficial urothelial tumors, bladder neck incision (BNI), and surgical management of BPH [7–11].

The combination of the Nd:YAG laser with the Ho:YAG laser was used early to vaporize and coagulate tissue using a technique known as combination endoscopic laser ablation of the prostate (CELAP). The initial experience of this technique was first reported by Gilling *et al*. who found the use of the Nd:YAG laser lead to a longer catheterization time, delayed symptom improvement, and high recatheterization rate (26%). These side effects limit the usefulness of this technique, and CELAP has been replaced by the holmium-only technique [12, 13].

Since its first use in 1994, different techniques using the holmium laser wavelength have been used in the surgical management of BPH: holmium laser ablation (HoLAP), resection (HoLRP), and enucleation of the prostate (HoLEP).

Physics

Every new laser technology has specific advantages; however, its physics may result in significantly different outcomes. The holmium:yttrium–aluminum–garnet

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Smith's Textbook of Endourology, Third Edition. Edited by Arthur D. Smith, Gopal H. Badlani, Glenn M. Preminger, Louis R. Kavoussi.
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(Ho:YAG) laser emits a pulsed, invisible infrared beam with a wavelength of 2140 nm, which is absorbed strongly by water (which constitutes 60–70% of the prostate). The depth of penetration is 0.4 mm, which predominantly causes vaporization without a deep coagulation zone when used with a side-firing fiber, and provides a precise incision and enucleation while maintaining hemostasis when used with an end-firing fiber. Energy absorption by the irrigant forms a vapor bubble around the laser fiber tip and this results in a microexplosion, causing a jackhammer effect that can cut tissues or disintegrate stones when in close contact to the target tissue [14]. If direct contact is not adequately maintained, laser efficiency will be reduced due to consumption of energy in the formation of vapor bubbles.

Surgical indications

Patients with lower urinary tract symptoms secondary to BPH causing bladder outlet obstruction are good candidates for holmium laser prostatectomy. HoLAP or HoLEP can treat glands of small-to-moderate size (<60 g), but larger glands are best treated by HoLEP.

Patients with more comorbidities or on anticoagulant medication are treated effectively with the holmium laser even while continuing their medications [15] In addition, the physical properties of holmium allow simultaneous transurethral cystolithotripsy during holmium laser prostatectomy [16].

Hip mobility problems secondary to degenerative disease, which will not allow patients to be placed in an adequate lithotomy position, are a relative contraindication for HoLEP.

Surgical management of benign prostatic hyperplasia

Holmium laser bladder neck incision

This technique uses the holmium laser energy to perform single or bilateral incision of the bladder neck. This is best suited to small glands with an elevated bladder neck and short prostatic urethra. Holmium laser bladder neck incision (HoBNI) can be performed as a catheter-free outpatient procedure. Cornford *et al*. confirmed the effective and durable results of this technique: at 2-year follow-up, the mean maximum renal flow rate (Qmax) increased from 9.7 to 18.2 mL/s [17].

Holmium laser ablation of the prostate

In 1994, HoLAP using a side-firing fiber was the first procedure using the holmium wavelength alone for laser prostatectomy. HoLAP is easy to learn, but it requires a longer operating time [18, 19]. For HoLAP, a 80–100-W holmium laser generator and 550-μm side-firing laser fiber are frequently used. The settings for HoLAP range from 2 J and 50 Hz to 3.2 J and 30 Hz, without the need for any tissue retrieval instruments. HoLAP is performed with the patient under general or regional anesthesia and normal saline is used as the irrigant.

Vaporization of the prostate usually starts at the bladder neck using the side-firing laser fiber to make a BNI at 5 and 7 o'clock; then the laser fiber is gently moved over the surface of the obstructed lobe towards the apex of the prostate proximal to the verumontanum. The end-point of the laser procedure is a TURP-like cavity lined by capsular fibers.

In a randomized trial comparing HoLAP and TURP in men with prostates smaller than 60 mL, the subjective and objective improvements in both group were similar at 1-year follow up. However, the advantages of HoLAP over TURP included less dysuria and bleeding, and shorter hospital stay and catheter time, without need for any irrigation [20].

HoLAP achieves durable relief of bladder outlet obstruction and urinary symptoms. At 7-year follow-up of 34 patients who underwent HoLAP, there was an 83% improvement in Qmax, a 47% decrease in symptom score, reoperation rate of 15%, and recatheterization rate of 9% [21].

McGill University Health Center (MUHC) reported on 109 patients who were randomly assigned to undergo either HoLAP or photoselective vaporization of the prostate (PVP) with a follow-up period of up to 4 years. The early results of this study confirmed that both techniques are safe and effective in small-to-moderate size prostates; however, HoLAP required a longer operating time by 14 min [19] Subjective and objective voiding parameters showed significant improvement, lasting for up to 3 years and confirming the long-lasting and durable effects of both techniques. At 3-year follow-up, mean International Prostate Symptom Score (IPSS) improved by 69.5% and 63.6% and mean Qmax increased by 164% and 190% in the HoLAP and PVP groups, respectively. The overall retreatment rate for urethral stricture, bladder neck obstruction, and residual adenoma was 15.8% versus 19.3% in the HoLAP and PVP group, respectively. The reduction in prostate-specific antigen (PSA) was 47.8% and 28.6% in the HoLAP and PVP groups, respectively, which reflects the incomplete removal of adenomatous tissue. The incidence of retrograde ejaculation in sexually-active patients was 12 of 33 (36.3%) in the HoLAP group compared to 13 of 30 (43.3%) in the PVP group. There was no significant difference between preoperative and postoperative sexual function.

Kumar reported on a series of 17 patients with a prostate volume greater than 80 mL treated with a 100-W holmium laser [22]. He noted that the mean percentage improvement in the American Urological Association (AUA) symptom score and Qmax was 70% and 217%, respectively, with a 55% reduction in prostate volume. In addition, the incidence of bladder neck contracture was 5% with no stricture urethra reported; however, the small number of patients in this study was a limiting factor.

The vaporization techniques are best suited to small or moderate sized prostates; larger prostates will necessitate a much longer operative time and the use of more than one fiber, with more patients having to undergo reoperation. Thus, for large prostates, HoLAP may not be economic when compared with standard TURP [22]. Further studies are needed to assess the effectiveness, safety, and durability of this technique in the management of large-sized prostates.

A controversial issue related to HoLAP when compared to TURP is the lack of tissue for histopathologic examination, which could lead to diagnoses of prostatic carcinoma being missed. Therefore, it is mandatory to perform a thorough evaluation of patients with an elevated PSA level or abnormal digital rectal examination (DRE), with transrectal ultrasound (TRUS)-guided biopsies prior to the intervention. It is also mandatory to continue postoperative PSA and DRE surveillance.

Holmium laser resection of the prostate

Before the development of the morcellator, Gilling *et al*. developed a technique that aimed to resect prostatic tissue by the holmium laser, similar to TURP. The resected pieces were small enough to be retrieved by a modified resectoscope loop or Ellik evacuator.

HoLRP starts with bilateral incision to define the depth and amount of tissue to be removed. The next step is to join the two incisions just in front of the verumontanum to undermine the median lobe and deposit it into the bladder. Incisions at 1 and 11 o'clock position over the entire length of the prostate are needed to define the upper margin of the excision of the lateral lobes. Dissection occurs precisely in the plane between the adenoma and capsule in a retrograde fashion until only a bridge of tissue remains at the bladder neck [11]. The technique of HoLRP produces a cavity identical in appearance to TURP, but with a relatively bloodless procedure that results in a short catheter time, immediate functional improvement, and minimal postoperative irritative symptoms. In 1996, Gilling *et al*. reported in a series of 84 patients that mean AUA score improved from 21.3 preoperatively to 7.6 at 1 month and 4.1 at 3 months. The mean Qmax increased from 7.5 mL/s preoperatively to 17.8 mL/s at 1 month and 19.3 mL/s at 3 months. Two patients (2%) required bladder irrigation for significant hematuria perioperatively and four patients (5%) required recatheterization; a few patients reported mild irritative urinary symptoms [11].

A prospective randomized study in 1999 compared HoLRP to TURP for the surgical management of symptomatic BPH [23]. Both techniques resulted in significant improvements in symptom score, quality-of-life (QoL) score, Qmax, and postvoid residual urine (PVR). Operative time was significantly longer in the holmium group but perioperative morbidity, catheter time, nursing contact time, and hospital stay were significantly less for HoLRP compared to TURP. The long-term results of this randomized trial in 2004 confirmed the long-lasting effect and durability of this technique in terms of symptom score and flow rate [24].

Holmium laser enucleation of the prostate

There is a persistent interest in HoLEP as the new gold standard for the surgical management of BPH in prostates of any size, replacing open prostatectomy and TURP [25]. Results from many studies, including randomized trials and systematic reviews, have confirmed the effectiveness and durability of HoLEP, as evidenced by functional outcomes, PSA data, TRUS, weight of tissue resected, and urodynamic parameter [26–31]. HoLEP has allowed patients who traditionally required open prostatectomy the alternative of being treated endoscopically with minimal blood loss, and short catheterization time and hospital stay [32]. It also provides optimal tissue for histopathologic assessment.

HoLEP reproduces the removal of the obstructing prostatic tissue with a true anatomic surgical enucleation of the adenoma, identical to using the index finger in open prostatectomy. The introduction of the tissue morcellator facilitates faster removal of the prostatic adenoma enucleated from the bladder.

Instruments and technique

The equipment consists of a 26F continuous flow resectoscope sheath with a modified inner sheath and a terminal bridge, through which 5F or 7F catheters are introduced to hold and stabilize the end-firing laser fiber. The high power pulsed 80–100-W holmium laser unit (Lumenis, Santa Clara, CA, USA) is frequently used with a 550-μm end-fire laser fiber. The laser is set at 2 J and 40–50 Hz. The Versacut morcellator (Lumenis) is introduced through a long nephroscope and an adaptor (Karl Storz, Tuttlingen, Germany) is used for tissue retrieval.

The enucleation procedure has been well described by Gilling [32] and Fong and Elhilali demonstrated the procedure in a video article [33]. Recently, we introduced some technical refinements in the HoLEP technique that may decrease the operative time and learning curve; these are available for review online [34].

The advantages of this technique include an almost bloodless field, allowing better vision with simultaneous coagulation of all bleeding vessels. Moreover, the dissection can be sharp or blunt. Three-dimensional awareness and hand–eye coordination are mandatory in this technique. The visibility in HoLEP, compared with standard TURP, is much better because of the bloodless field and the greater image magnification.

Two techniques are used for HoLEP based on the anatomy and size of the middle lobe. In general, a two-lobe technique should be attempted whenever there is only a single or no deep groove at the 5 or 7 o'clock positions of the bladder neck (as in the majority of cases). This lowers the risk of undermining the trigone. The three-lobe technique is used only when there is a large median lobe with deep grooves on both sides.

Enucleation is done using a combination of blunt and sharp dissection in a retrograde fashion. The blunt enucleation is achieved by using the tip of the scope, just like using a finger, to separate the adenoma from the surgical capsule in a technique similar to the traditional retropubic prostatectomy but in a retrograde manner. The operator should always use a rotating movement to follow the contour of the prostate and care must be taken to avoid using excessive force so as not to unnecessarily stretch the external urinary sphincter. Blunt enucleation should be avoided if the tissues do not separate easily. Instead, the laser should be used to cut any attachments. The proper plane can be identified from its appearance, as well as from the ease with which the tissues separate (see Video 1.1). A modification we are proposing is that when the adenoma is separated laterally and the anterior aspect of the prostate is reached, the dissection is extended across the midline in order to facilitate the later separation of the two lobes in the midline anteriorly when the 12 o'clock incision is performed, eliminating any guess work about the depth needed (see Video 1.2). Once the anterior incision is made, the only attachment that the adenoma has should be the apical mucosal strip at the level of the urinary sphincter. This is carefully incised using short energy bursts at settings of 1.5 J at 30 Hz for an energy level of 45 W, to minimize the risk of thermal damage to the sphincter (see Video 1.3).

The lateral lobes are gently pushed into the bladder. Finally, morcellation of the prostate is performed inside the bladder. Special emphasis is placed on achieving excellent hemostasis before starting morcellation because the visibility with the indirect nephroscope is not as good as with the cystoscopic lens. When coagulating a bleeding vessel, the laser fiber is unfocussed but directed end-on towards the bleeding point. A whitening of the tissue around the vessel can often be used as an indicator of adequate coagulation. Morcellation is one of the most critical steps of the procedure and is often considered potentially dangerous. In order to avoid complications, two principles need to be strictly observed. First, the patient's bladder should be adequately distended. This is achieved by ensuring that the patient's abdominal muscles are relaxed and that the irrigation inflow is not interrupted. Second, the morcellation process should always be performed under direct vision. This is achieved by having adequate hemostasis and by keeping the engaged piece directly in front of the lens of the nephroscope, with the nephroscope tip and cutting blades in the middle of the bladder (see Video 1.4)

Before the availability of tissue morcellators, some authors performed a mushroom technique. Fragmentation of the lobes was performed by traditional electrocautery loop resection whilst the devascularized lobes were still connected to the surgical capsule by a narrow pedicle [30].

Postoperative care

At the end of the procedure, a 20–22F, 30-mL balloon two-way Foley catheter is inserted. Sometimes a stylet is needed to insert the catheter. The catheter is fixed to a Y-connector, which is used to deliver intermittent irrigation to the bladder if needed in the recovery room. Rarely, a three-way catheter and continuous bladder irrigation are used. The catheter is removed on the next morning unless otherwise indicated and the patient is discharged. Some urologists discharge patients on the same day without a catheter, but this practice is usually limited to HoLAP or small volume HoLEP.

Safety

Recent reports on HoLEP have confirmed its safety for different prostate sizes, with no size limits, and with low morbidity and short catheterization time and duration of hospitalization.

Naspro *et al*. performed a randomized study comparing HoLEP to open prostatectomy in 80 patients (41 vs 39 patients, respectively) with a prostate size greater than 70,g [26]. HoLEP was shown to be safer than open prostatectomy in the perioperative period, requiring a lower number of blood transfusions (4% vs $P < .001$) in addition to a shorter catheterization time (1.5 vs 4.1 days, $P < 0.001$) and hospital stay (2.7 vs 5.4 days, $P < 0.001$). However, time in the operating room was significantly longer for the HoLEP group (72 min) than the open prostatectomy group (58 min) ($P < .0001$). Furthermore, the authors reported a 7.3% bladder mucosal injury rate in the HoLEP, and the early acute urinary retention rate was 12.1% (vs 5.1%in the OP group, P = 0.11).

Shah *et al*. performed a prospective study evaluating the perioperative complications in 280 patients undergoing HoLEP [35]. Blood transfusion was required during HoLEP in one patient; other complications included capsular perforation (9.6%), superficial bladder mucosal injury (3.9%), and ureteric orifice injury (2.1%). A blood transfusion was needed after HoLEP in 1.4% of patients with clot evacuation in 0.7% by cystoscopy.

Bladder mucosal injury is a potential complication related to morcellation, and can be avoided by effective hemostasis and adequate bladder distention prior to morcellation. Care must be taken not to engage the bladder mucosa during the suction phase. Rieken *et al*. recently extensively reviewed data published between 2003 and 2006 [36]. They reported capsular perforation rates ranging from 0.3% to 10%; these were usually small capsular lacerations that did not require further management. Bladder injury is reported in 0.5–18.2%, with superficial mucosal injury requiring no additional treatment in most cases. Rates of superficial ureteric orifice injury not requiring insertion of a ureteral stent or nephrostomy tube ranged from 1.0% to 2.1% and incomplete morcellation from 1.9% to 3.7%, and cardiac events were reported in up to 1.2% of patients undergoing surgery. The authors demonstrated a correlation between the incidence of such complications and the level of experience of the surgeon. In addition, they found that prostate size had no statistically significant influence on intraoperative complications: capsular perforations were more likely associated with smaller prostates, while injury of the ureteric orifice occurred mainly during resection of large median lobes protruding into the bladder.

TURP in patients with BPH on anticoagulant therapy is frequently avoided due to the higher perioperative morbidity. It is also associated with an increased incidence of perioperative hypercoagulability state, with an overall 8% incidence of deep vein thrombosis after TURP [37, 38]. HoLEP has been shown to be a safe and effective therapeutic modality in patients on anticoagulation with symptomatic BPH refractory to medical therapy. Elzayat *et al*. performed a retrospective study of 83 patients who were on chronic oral anticoagulant therapy or had bleeding disorders and underwent HoLEP with a mean prostate size of 82.4 mL [15]. A total of 14 patients underwent HoLEP without oral anticoagulant withdrawal, 34 underwent surgery with low molecular weight heparin substitution, and 33 stopped anticoagulants a few days before surgery and restarted them immediately after surgery, including eight on antiplatelet therapy. One patient required intraoperative platelet transfusion and seven required blood transfusion early in the postoperative period due to hematuria coinciding with restarting oral anticoagulant therapy. There were no major operative or postoperative complications, or thromboembolic events.

Early efficacy

HoLEP produces immediate and sustained improvement of objective and subjective outcomes similar to both open prostatectomy and TURP. The pre- and postoperative urodynamic assessment has confirmed that the relief of obstruction with HoLEP is superior to, or at least equivalent to, TURP and open prostatectomy [27, 30, 39].

Wilson *et al*. compared the functional outcomes of HoLEP to TURP in a randomized study of patient with a prostate size of 40–200 g. At 1-month follow-up, functional outcomes in terms of AUA score (8.6 vs 5.7) and Qmax (22.3 vs 18.4 mL/s) were observed in the HoLEP and TURP groups, respectively [27]. The improvement in functional outcomes was maintained for up to 24 months. In 2007, Ahyai *et al.* published interesting data regarding the efficacy of HoLEP compared to TURP [28]. A total of 200 patients with a prostate volume of less than 100 mL were prospectively randomized to HoLEP or TURP and followed up for up to 3 years. At 2- and 3-year follow-up, HoLEP micturition outcomes compared favorably with those of TURP. The AUA score was significantly better at 2 years postoperatively in the HoLEP group (1.7 vs 3.9, $P < .0001$) and similar at 3 years (2.7 vs 3.3, $P = .17$). PVR was significantly better at 2 years (5.6 vs 19.9 mL, $P < .001$) and 3 years (8.4 vs 20.2 mL, $P = .012$) postoperatively in the HoLEP patients. However, Qmax was similar in the HoLEP and TURP groups at 2 years (28.0 vs 29.1 mL/s, $P = 0.83$) and at 3 years (29.0 vs 27.5 mL/s, $P = 0.41$) postoperatively.

In comparing HoLEP to open prostatectomy, Naspro *et al*. demonstrated equivalence in terms of improvement in obstruction, starting with the 3-months follow-up and reaching a plateau at the 24-month follow-up [26]. At 24 months, Qmax had improved to clinically normal levels in both the HoLEP and open prostatectomy groups (19.19 vs 20.11 mL/s, $P < 0.9$, respectively).

Kuntz *et al.* confirmed the previously reported data on large prostates in a randomized trial in patients with prostates larger than 100 g [40]. Both HoLEP and open prostatectomy resulted in effective and long-lasting postoperative improvements in symptom scores, Qmax, and PVR. The differences between HoLEP and open prostatectomy in functional outcomes were not significant at each time point during follow-up.

Early postoperative stress incontinence occurs as a rare event after HoLEP and is reported in around 2% of cases, which is comparable with results from TURP and open prostatectomy [28, 41].

Urinary retention

Patients with urinary retention represent a particular challenge to urologists, as they often experience inferior functional outcomes and a higher complication rate when compared to patients without urinary retention. Peterson *et al*. retrospectively evaluated 164 patients in urinary retention treated by HoLEP [42]. Mean duration of urinary retention was 28.9 days (range 2–365 days). Their results confirmed the safety and reliability of this procedure for treating urinary retention in men with large prostates. All patients were able to void following treatment and remained catheter free. Mean urine flow rate was 26.7 mL/s (range 4.3–54.8 mL/s) and mean PVR was 32.5 mL (range 0–150 mL). The outcome for patients with chronic urinary retention and hypotonic bladder may be less satisfactory.

Late efficacy and durability

Sufficient data prove HoLEP's durability for most prostate sizes at long-term follow-up (Figure 127.1). Gilling *et al*. recently published 6-year data, demonstrating persistent reductions in IPSS scores (8.5 vs 25.7) and QoL score (1.8 vs 4.9), and improvements in Qmax (19 vs 8.1 mL/s), with a 92% overall satisfaction rate with the results [29]. Elzayat and Elhilali confirmed that Qmax increased by 204%, PVR declined by 81%, and IPSS decreased by 67.6% during 5-year follow-up [43]. The improvement in outcome parameters was durable and the late complication rate was very low.

Kuntz *et al*. reported their 5-year follow-up results in a randomized clinical trial comparing HoLEP to open prostatectomy [30]. Interestingly, mean AUA score was 3.0 in both groups ($P = 0.98$), mean Qmax was 24.4 mL/s in both groups ($P = 0.97$), and PVR was 11 mL in the HoLEP and 5 mL in the open prostatectomy group ($P = 0.25$). Late complications included urethral strictures and bladder-neck contractures; the overall reoperation rates were 5% in the HoLEP and 6.7% in the open prostatectomy group ($P = 1.0$). BPH did not recur in any patient.

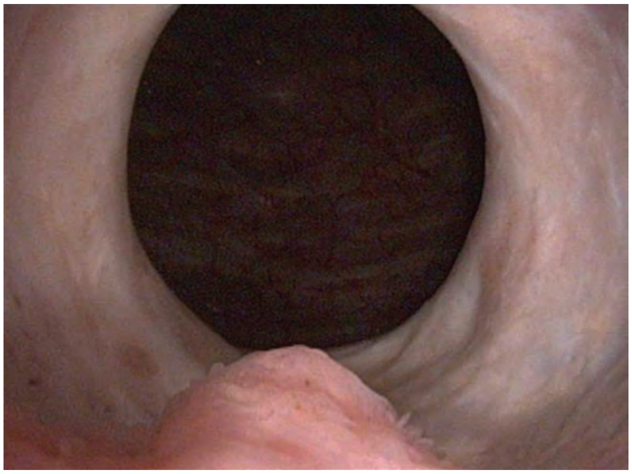

Figure 127.1 Cystoscopy 6 years post HoLEP.

Urethral strictures have been reported in 1.4–4.1% of cases and bladder neck contractures in 0–5.4% (Table 127.1). The reintervention rate due to residual tissue is very low (0-5.4%) over a follow-up period of up to 7 years [43, 44].

Prostate-specific antigen reduction

Measurement of PSA may be a useful surrogate tool for the objective assessment of the amount of residual prostatic tissue following different therapies for BPH. It has been reported that serum PSA level is markedly reduced after open prostatectomy or transurethral surgery, as the transition zone is the major source of PSA production. Stamey *et al.* reported the changes in PSA after open prostatectomy or transurethral procedures for the treatment of BPH [45]. There was a mean decrease in PSA of 95% in the open prostatectomy group and of 84% in the TURP group (73 men). Others have confirmed a mean percentage PSA reduction of 70– 75% after TURP [46].

HoLEP produces a significant reduction in PSA that correlates well with the weight of adenoma resected (Figure 127.2). Tinmouth *et al.* examined PSA data before and after HoLEP from two institutions performing high volumes of this procedure in a retrospective evaluation of 509 patients [47]. The average weight of adenoma resected was 49.8 g (range 5–300 g) in the McGill group

Table 127.1 Causes of retreatment following treatment with HoLEP.

	Urethral stricture (%)	Bladder neck contracture (%)	Residual adenoma (%)
Naspro *et al.* [27]	2.8	5.4	5.4
Wilson *et al.* [28]	3.2	0	0
Elzayat *et al.* [43]	1.6	0.8	4.2
Ahyai *et al.* [29]	4.1	3.1	1
Shah *et al.* [35]	2.1	0.4	0
Gilling *et al.* [30]	1.4	0	1.4
Kuntz *et al.* [31]	3.3	1.7	0

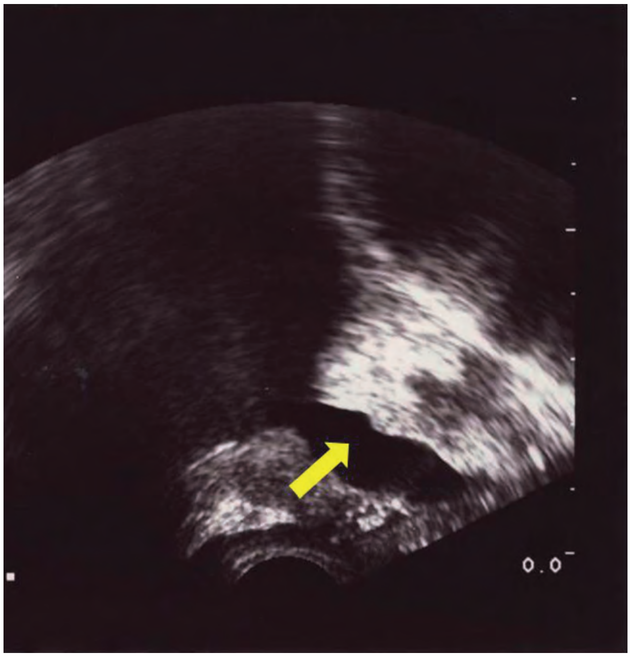

Figure 127.2 Adenoma weight on Transurethral ultrasound (TRUS) 6 months after HoLEP (adenoma weight 24 g, compared with 140 g preoperatively. The entire resected channel through the prostatic urethra can be well identified after HoLEP (arrow).

and 90.4 g (range 7.9–312 g) in the Methodist Hospital group, and the mean decrease in PSA 81.7% and 86%, respectively.

Elmansy *et al*. evaluated 335 patients treated with HoLEP between 1998 and 2006 in a longitudinal study [48]. They found that the mean PSA dropped from 5.44 to 0.91 ng/mL and the mean PSA reduction was 75.4%, indicating that HoLEP is an effective technique in near complete adenoma resection. Moreover, this percentage reduction in PSA was maintained for up to 7-year follow-up, suggesting that the reduction in gland size after HoLEP is durable and more complete, which could explain the lower reoperation rates previously reported for residual tissue. In addition, they proposed that if the reduction of PSA after HoLEP is less than 50%, closer follow-up with PSA measurements every 3–6 months for the first 2–3 years is indicated to allow earlier detection of prostate cancer.

Sexual function

Only two randomized clinical trials have specifically evaluated sexual function following HoLEP. Briganti *et al*. evaluated 120 patients in a prospective two-center randomized trial comparing the impact on sexual function of HoLEP versus TURP [49]. According to the International Index of Erectile Function (IIEF) score, HoLEP and TURP had a similar limited impact on erectile function with a slight but nonsignificant improvement. It seems that the cessation of preoperative medications, such as finasteride and alpha-blockers, and/or the improvements in the functional urinary outcomes may be related to this improvement. Both techniques significantly decreased the score for the orgasmic function domain, due to retrograde ejaculation in 78.3% in both groups after 2-year follow-up. Moreover, no significant differences were found between preoperative and postoperative sexual function regarding intercourse satisfaction, sexual desire, and overall satisfaction.

Comparing HoLEP to open prostatectomy, Naspro *et al.* were able to demonstrate equivalence in terms of sexual function after both procedures [26].

Gilling *et al*. reported a 76% rate of retrograde ejaculation after HoLEP that lowered the orgasmic function domain without affecting the other IIEF domains, such as intercourse satisfaction, sexual desire, and overall satisfaction, confirming that retrograde ejaculation is less likely to have a negative impact on overall sexual life satisfaction [29].

Learning curve

While HoLAP is a simple and easy to learn technique that can be mastered in a few cases, adoption of HoLEP has been limited by its steep learning curve, a limitation often stated by the urologists [33]. HoLEP requires longer training than standard TURP. Extensive experience with transurethral surgery and the supervision of an experienced urologist are mandatory to master this technique. In particular, the initial apical enucleation and incision of anteroapical mucosal attachments of the lateral lobes are difficult to master.

Elhakim and Elhilali presented the initial experience of a senior urology resident with HoLEP. He treated 27 patients with a mean prostate size of 54.8 g under the supervision of an experienced urologist. His overall results were comparable with those reported for the supervisor. They found that an average of 15–20 cases is needed for the trainee to feel confident with the technique [50].

However, Shah *et al*. reported that an endourologist inexperienced with HoLEP can perform the procedure with reasonable efficiency after about 50 cases, with an outcome comparable to that of the experts [51]. A higher incidence of complications, including capsular perforation and stricture urethral stricture, was seen in first 50 cases, with enucleation efficiency reaching a plateau after 50 cases. There was no significant difference in the functional parameters between the first cases and the last 62 cases.

Seki *et al.* also showed that significant relief of symptoms and urodynamic parameters can be achieved even very early in a urologist's experience [52]. However, the authors concluded that enucleation efficiency was likely to be associated with a learning curve of up to 50 cases, as the average enucleation efficiency was 0.29 g/min for the first 10 cases but 0.75 g/min by the 70th case.

Elzayat *et al*. performed a retrospective study evaluating 118 patients who underwent HoLEP and compared the results for the first 50 patients with a later group of patients [43]. There was no significant difference in the enucleation and morcellation times in both groups. However, the retreatment rate after 5 year follow-up in the earlier group was higher (8% vs 1.4%).

New practitioners need a high volume cases to become familiar with this technique. Urologists who do not treat enough cases to maintain a reasonable operative frequency will have a longer learning curve that could be reflected in their complication rate [53]. We feel that it is also important in the learning process for the procedures to be carried out at short intervals, so as to build on experience rather than starting from the beginning each time.

Cost

HoLEP has been shown to be more cost-effective than open prostatectomy. Salonia *et al.* analyzed the inpatient costs of HoLEP compared to open prostatectomy [54]. They found that the hospitalization cost of HoLEP was 9.6% less than that for open prostatectomy. The cost reduction is mostly related to the shorter hospital stay and the significant reduction of blood loss, which eliminates the need for blood transfusion. In addition, one advantage of HoLEP that could affect the final cost is that the same fiber can be used up to 20 times.

Fraundorfer *et al* demonstrated that HoLEP was more cost-effective than TURP at 1-year follow-up, considering perioperative data and complication rate with the subsequent unplanned clinic visits and readmissions [55].

Histology and morcellation

The vaporization and coagulation effects of HoLEP and use of morcellation raise a concern about the ability of the histopathologist to accurately assess the adenoma specimen. In a prospective study comparing histologic findings of HoLEP and TURP, Naspro *et al*. confirmed that general prostatic architecture is maintained in the majority of HoLEP histologic specimens without affecting the ability to detect incidental prostate cancer and prostatic intraepithelial neoplasia [56].

Conclusions

Different types of lasers have been used to perform laser prostatectomy and give comparable and durable result similar to TURP with minimal morbidity, short catheterization time, short hospital stay, and low reoperation rate with no significant complications. The holmium laser has been effectively used for many urologic applications.

HoLEP seems to offer the most favorable functional outcomes in terms of subjective and objective parameters with no prostate size limitation. Emerging data have confirmed this technique to be durable with an overall low reoperation rate. For other modalities, long-term follow-up and randomized comparative studies are still needed to confirm the effectiveness and durability of each technique.

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CHAPTER 128

532-nm High-Power Transurethral Laser Prostatectomy

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Introduction

Lasers have evolved from theory to practical application. One use is the treatment of symptomatic benign prostatic hyperplasia (BPH) via laser prostatectomy. Traditionally, the gold standard for treatment of BPH is the electrocautery-based transurethral resection of the prostate (TURP). TURP, however, is associated with several complications and side effects, including fluid absorption, electrolyte imbalance, intraoperative and postoperative bleeding, and inadequate resection. Laser therapy has several advantages over standard TURP, including technical simplicity and the absence or minimization of complications such as intraoperative fluid absorption, bleeding, retrograde ejaculation, impotence, and incontinence. Laser therapy may also result in a shorter hospital stay and recovery. Less bleeding and irrigant absorption theoretically allows laser prostatectomy to treat larger glands with less physiologic stress, suggesting a role for laser therapy in patients with a high burden of coexisting medical disease. Recent estimates suggest an increasing number of practicing urologists are in fact already performing laser prostatectomies on patients with symptomatic BPH. Furthermore, the techniques and lasers used for laser prostatectomy are constantly evolving. To fully understand the mechanism of laser interaction with prostate tissue, some basic laser principles must first be understood.

Laser physics

The word "laser" actually represents an acronym, standing for light amplification by simulated emission of radiation (LASER). An external energy source is used to excite electrons in a medium with an inherently large population of unstable electrons, causing the electrons to reach a higher energy state, called a metastable level. As the electrons return to ground state, they release an amount of energy equal to that initially absorbed, resulting in the spontaneous emission of photons [1–3] . Unlike normal white light, which is comprised of the entire visible electromagnetic spectrum, laser energy is monochromatic, i.e. all of its photons originate from the same energy level transition with both spatial and temporal coherence [1–3] . Additionally, laser rays are parallel to each other and hence do not converge or diverge unless reflected or focused by a lens or mirror. However, once transmitted through flexible fibers by internal reflection, the laser beam will become divergent as it exits the fiber.

Laser energy affects tissue by inducing coagulation, vaporization, or even a mechanical tearing of tissue [4]. Power directly influences the temperature level reached and the speed with which a surgical effect is achieved. Generally, a temperature of greater than 50°C is required to produce a coagulative effect, while a temperature of greater than 100°C is required to produce a vaporization effect. Medical laser sources usually possess a maximum power output of 20–100 W, although some newer sources can reach a power of 180 W.

Power density, defined as power per unit area (P/A), represents the most important parameter that expresses the strength of the laser at a fixed location. Fibers with narrowly divergent beams will have a much higher power density than fibers with widely divergent beams due to the difference in the size of target areas. As a

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corollary, this also implies that maximum power density arises when the tip of a laser fiber is almost in contact with tissue, i.e. at the distance where divergence is minimized [1–3, 5, 6].

Laser–tissue interaction

Four major interactions occur when laser energy is applied to human tissue.

Reflection

Up to 50% of the incident energy of a laser beam is reflected away. After the initial reflection, the remaining energy is then transmitted through the tissue for a specific distance, depending upon the type of laser used as well as the particular type of tissue being treated. After absorption, the laser energy is then converted to thermal energy, or heat.

Scattering

As laser energy strikes the irregularities of a tissue surface, diffuse reflection, also known as scattering, occurs. Scattering may occur in either forward or backward directions. The amount of scatter that occurs depends on tissue characteristics such as water content, cell constituents, and pigments. Scattering also depends on the resonant absorption and re-emission of radiation by the atoms of the receiving tissue, as well as the diffraction or radiation of laser energy in directions away from the line of propagation. As a result of scattering, a laser beam does not merely continue to penetrate in a straight line but dissipates its energy within the surrounding area, beginning when it hits the first tissue interface and continuing to create a zone of heat along the path of the beam.

Penetration

Laser energy may alternatively penetrate tissue. The depth of penetration by laser energy depends on its wavelength and the composition of the receiving tissue. Penetration is often described by "extinction length," the depth of penetration of an incident beam beyond which only 10% of the initial beam energy is left, i.e. 90% absorption. Therefore, after one extinction length, 10% of the beam will penetrate further, whereas after two extinction lengths, 1% of the beam will penetrate further, and so on.

Absorption

Laser energy may finally be absorbed by tissue. Absorption of laser energy is often described by "absorption length," the depth of tissue through which 63% of the incident beam energy is absorbed. It is important to note that the different components of living tissue absorb different laser energy wavelengths in variable fashions. Water, constituting 75–85% of soft tissue, absorbs 532-nm laser energy very poorly, resulting in deep penetration of the laser beam into tissue. Pigments, such as hemoglobin, bilirubin, and melanin absorb 532-nm energy very efficiently. Finally, carbon, an abundant constituent of all living tissue, is a final breakdown product of pyrolysis and represents a strong absorber of all wavelengths of laser energy.

532-nm laser

The original 532-nm laser was a potassium–titanyl–phosphate (KTP)-based laser system that contained a KTP crystal through which a 532-nm wavelength was generated. This had a different interaction with prostate tissue from its parent, the neodymium:yttrium–aluminum–garnet (Nd:YAG) [7]. The 532-nm wavelength is selectively absorbed by hemoglobin, which acts as an intracellular chromophore. The 532-nm laser energy can be fully transmitted through aqueous irrigants into the cell where it is absorbed by hemoglobin, which is then rapidly heated, leading to vaporization of prostate tissue. The short optical penetration that is associated with this wavelength confines its high-power laser energy to a superficial layer of prostate tissue that is vaporized rapidly and hemostatically, with only a 1–2-mm rim of coagulation. The thin coagulation zone arises as a result of the quasi-continuous emission characteristics of the 532-nm laser. Typically, continual irradiation of a single point causes heat to diffuse into deeper tissue layers, causing coagulation wherever there is enough convection thermal energy for protein denaturation but insufficient energy for vaporization. These selective characteristics led to the use of the 532-nm laser in prostatectomy, coined "photoselective vaporization of the prostate" (PVP).

Historically, initial trials involved the comparison of the 532-nm KTP-based laser with the Nd:YAG laser in 41 canines [7]. Both techniques were hemostatic in nature, with no irrigant absorption detected. KTP laser vaporization produced a prostatic defect with a mean diameter of 3.0 and 2.4 cm at 2 days and 8 weeks postoperatively, respectively. Statistically smaller defects were produced by Nd:YAG laser vaporization (2.0 and 1.4 cm, respectively) and coagulation (0.5 and 0.9 cm, respectively). None of the dogs treated with KTP laser vaporization was incontinent or developed urinary retention postoperatively. The use of the KTP laser thus appeared safe and effective in small-scale animal series.

60-W data

Experiments with a higher power 60-W KTP laser began with both *in vivo* canine studies as well as cadaveric canine and human trials [8]. These studies proved the ability of the KTP laser to vaporize tissue while minimizing accompanying coagulation effects. The first human trials with the 60-W KTP laser were conducted in a series of 10 patients described by Malek *et al*. in 1998 [9]. No patients suffered postoperative TUR syndrome or urinary retention; in fact, all patients were catheter free within 24 h after the procedure. Patients experienced a significant improvement in maximum renal flow rate (Qmax) (142%) by 24 h postoperatively. Though the follow-up described was preliminary in nature, initial results have suggested enduring results in terms of Qmax, mean American Urological Association (AUA) symptom score, and mean postvoid residual urine (PVR) at the 3-month follow-up. Mean operative time was 29 min.

These original human trials with the 60-W KTP laser were followed by a larger series of 55 patients in 2000 [10]. The 2-year experience with the higher powered KTP laser again corroborated initial findings. Patients experienced statistically significant, enduring improvements in postoperative AUA symptom score (mean 14, 82% improvement), Qmax (mean 29.1 mL/s, 278% improvement), and PVR (27 mL, 75% improvement) at 2 year follow-up, comparing favorably with published results for conventional TURP. Mean operative time was 44 min. All patients in the series were catheter free 24 h after the procedure; none required recatheterization or experienced TUR syndrome. Hematuria was negligible despite the use of antiplatelet agents by many patients. These results demonstrated that prostatectomy with the 60-W KTP laser was as effective as conventional TURP, and in fact demonstrated postoperative complications comparable to TURP and even to other laser therapies, such as the holmium:YAG.

80-W data

Despite the effectiveness of the 60-W KTP laser in prostatectomy, its less-than-ideal speed of vaporization inherently limited the size of prostate that could be resected. The next logical improvement therefore lay in increasing the laser power to speed tissue ablation. It is interesting to note that to preserve a thin coagulation zone while maintaining high vaporization efficiency, a unique laser pulsing technology was incorporated into the 80-W higher power KTP laser system. A high frequency modulation of laser light generates a continuous stream of short micro-pulses with a duration of 4.5 ms and a peak power of 280 W, i.e. 3.5 times the average laser power of the regular 80-W laser. The short duration of the micro-pulses does not allow time for heat to diffuse from the superficial layer, thus confining energy to a small volume of tissue, a situation referred to as thermal confinement. As each micro-pulse generates a very fast temperature increase inside tissue, the tissue water is not only rapidly vaporized but the surrounding tissue matrix is torn apart, allowing for efficient removal of prostate tissue. Continuous bladder irrigation is thus required to cool the tissue as well as to provide a clear aqueous medium for laser light to be transmitted to target tissue without energy loss.

The first experiments with the higher powered (80 W) KTP laser began with *ex vivo* animal models [11]. Twenty perfused porcine kidneys were used as a model for human prostate tissue. High-power KTP laser resection was compared to high-frequency current, i.e. TURP-like, resection. The 80-W KTP laser technique showed a statistically significant decrease in hemorrhage ($P < .0001$) compared to traditional TURP-like resection, demonstrating that essentially bloodless ablation of tissue could occur.

Hai and Malek presented the first human experience with 80-W KTP laser prostatectomy [12]. Ten patients were followed for 1 year after their prostatectomy in a pilot study. Patients experienced statistically significant improvements in AUA symptom score (23.2 to 2.6), quality-of-life (QoL) scores (4.3 to 0.5), Qmax (10.3 to 30.7 mL/s), and PVR (137.6 to 3 mL). The authors reported a 27% reduction in prostate volume. No patient experienced postoperative urinary retention, infection, incontinence, or erectile dysfunction; none subsequently developed bladder neck contractures or urethral stricture. Two patients in fact did not require postoperative catheterization at all. Only one patient, on active anticoagulation, experienced mild transient postoperative hematuria requiring recatheterization for 24 h. The mean operative time was 19.8 min.

Te *et al*. presented the first large, multicenter series on the use of the 80-W KTP laser in laser prostatectomy for 145 patients with long-term follow-up [13]. Of note, this experience represented the initial laser experience of this technology with these centers, testing ease of use. Significant and durable improvements in AUA symptom index (AUA SI) scores, QoL scores, Qmax, and PVR were demonstrated up to 12 months postoperatively. Mean AUA symptom scores declined from 24 to 1.8 at 12 months; mean QoL scores improved from 4.3 to 0.4, Qmax from 7.7 to 22.8 mL/s, and PVR from 114.2 to 7.2 mL. Mean prostate volume, as determined by ultrasound, decreased from 54.6 to 34.4 mL. Mean operative time was 36 min, and no patient required a blood transfusion. More than 30% of patients were sent home without a catheter; those with postoperative catheters had them removed in a mean of 14 h. Reported morbidities were generally minor; 8% of patients experienced mild-to-moderate dysuria lasting more than 10 days, 8% had transient hematuria, and 3% had postoperative retention. Among the 56 men who were potent prior to the procedure, 27% experienced retrograde ejaculation but none of them experienced impotence.

As a novel procedure, there are growing numbers of reports of long-term outcomes of 80-W KTP laser prostatectomy. Ruszat *et al*. published the largest series of 80-W KTP laser prostatectomies. At a single center, 500 patients underwent PVP, including 45% taking oral anticoagulation. After 3 years, 26.2% of patients had follow-up and mean AUS SI, PVR, and QOL were significantly improved compared to baseline. At 60 months, the retreatment rate was 6.8% and reoperation rate was 14.8%. Urethral and bladder neck strictures were observed in 4.4% and 3.6% of patients, respectively, comparable to the rate in TURP [14]. Te *et al.* reported 3-year multicenter long-term follow-up in 139 patients who underwent 80-W KTP laser prostatectomy. At 3 years, 33.8% of patients had follow-up and improvements in symptom relief and urinary flow rate were durable [15]. The retreatment rate was 4.3%.

One of the advantages of the 80-W KTP/532-nm laser is the ability to perform laser prostatectomy on larger glands with good outcomes and an excellent safety profile. Sandhu *et al*. detailed large prostate volume resection with the 80-W KTP laser [16]. Sixty-four men with BPH and prostates with volumes of at least 60 mL (mean 101 mL) who had failed medical therapy underwent vaporization with the 80-W KTP laser. The mean operative time was 123 min. The International Prostate Symptom Score (IPSS) decreased from 18.4 to 6.7 at 12 months; Qmax increased from 7.9 to 18.9 mL/s, while PVR decreased from 189 to 109 mL. No transfusions were required nor was there evidence of postoperative hyponatremia. All 62 patients were discharged within 23 h. This was the first evidence that the 80-W KTP laser could be used as a safe and effective therapy with durable results for large volume prostatectomy.

Pfitzenmaier *et al*. conducted a comparative study between vaporization of prostates greater than or equal to 80 mL (39 of 173 patients) and those smaller than 80 mL. The authors found that PVP was safe and effective in prostates greater than or equal to 80 mL but the reoperation rate was higher. In another study, Rajbabu *et al*. assessed 54 consecutive patients with prostates of greater than 100 mL who underwent 80-W KTP laser prostatectomy. Another recent study of 150 consecutive patients with lower urinary tract symptoms who underwent laser vaporization with the 80-W KTP laser showed a decrease in storage and voiding symptoms of 81.8% and 90.9%, respectively, at 12 months [17]. Consistent with other published series, these studies further support the procedure's safety, efficacy, and durable improvements on IPSS and QoL [18].

The safety of the 80-W KTP laser prostatectomy has been studied in patients at high cardiopulmonary risk, and demonstrated to be excellent due to the excellent hemostatic profile and perioperative hemodynamic stability of the procedure. Reich *et al*. performed 80-W laser prostatectomy on 66 patients with an American Society of Anesthesiology Score of 3 or greater [19]. Of these patients, 29 were being treated with ongoing oral anticoagulation or had a severe bleeding disorder. No major complications occurred during or following the procedure and no blood transfusions were required. Two patients required reoperation within 12 months due to recurrent urinary retention. Mean improvements in IPSS (20.2 to 6.5) and peak flow (6.7 to 21.6 mL/s) were durable at 12 months.

The final safety aspect of the 80-W KTP laser to be studied in detail was its use in anticoagulated patients at high risk for clinically significant bleeding. A series of 24 anticoagulated patients with BPH were treated with laser prostatectomy using the 80-W KTP laser [20]. Of these, eight were on warfarin, two on clopidogrel, and 14 on Aspirin. Eight (33%) of these patients had had a previous myocardial infarction; seven (29%) cerebrovascular disease, and seven (29%) peripheral vascular disease. No patients developed clinically significant hematuria postoperatively and none developed clot retention. No transfusions were required and there were no thromboembolic events.. Follow-up revealed a decrease in IPSS from 18.7 to 9.5, as well as an increase in Qmax from 9.0 to 20.1 mL/s at 12 months. PVR decreased from 134 to 69 mL at 1 month but this was not statistically significant beyond that time point. In this study, all patients underwent PVP safely without any adverse thromboembolic or bleeding events. Significantly, more energy and time were required for lasing per gland size in these patients [21].

There is a growing body of literature comparing 80-W KTP laser prostatectomy to TURP. Ruszat *et al*. conducted a study in 396 patients randomized to either 80-W laser prostatectomy or TURP [22]. Interim 24-month follow-up data found the rates of intraoperative bleeding (3% vs 11%), blood transfusion (0% vs 5.5%), capsule perforations (0.4% vs 6.3%), and early postoperative clot retention (0.4% vs 3.9%) were significantly lower in the laser group. There was no significant difference in IPSS and PVR. After 12 months, size reduction was greater in the TURP group (66% vs 44%) and the rate of repeat procedure was greater in the PVP group (6.9% vs 3.9%, not significant). Bouchier-Hayes *et al*. reported data on 120 patients randomized to undergo TURP or 80-W laser PVP [23]. At 12 months equivalent improvements in IPSS and flow rates were demonstrated. Length of hospitalization, length of catheterization, and adverse events were lower in the laser group. In a nonrandomized study, Bachmann *et al*. studied 101 patients who underwent either TURP or laser prostatectomy. Perioperative morbidity and symptom improvement was equivalent in the groups at 6 months [24]. Another randomized study has yielded divergent results. In this study, 76 patients with a prostate size of greater than 70 mL were randomized to TURP and 80-W laser prostatectomy [25]. Procedure time was shorter for the TURP group. Hospitalization stay and catheterization time were significantly shorter in the laser group. There was a significant difference in favor of TURP in terms of improvement in IPSS, PVR, and Qmax, as well as volume reduction. In addition, reoperation rate was higher in the laser group. An Australian study had similar results when comparing patients randomized to either 80-W laser prostatectomy or TURP [26]. Both groups showed a significant increase in mean urinary flow rate, improvement in IPSS scores, and no difference in sexual function at 1-year follow-up.

120-W data

The 80-W KTP laser system evolved to a higher power system (HPS) capable of 80–120 W. This laser emits the same 532-nm wavelength, with the same hemostatic properties as the 80-W KTP laser [27], but utilizing a different crystal. The 532-nm 80-W KTP laser is created by passing a 1064-nm Nd:YAG laser beam through a KTP crystal. In contrast, the 120-W HPS 532-nm wavelength is created by passing a Nd:YAG laser beam through a lithium triborate (LBO) crystal. The 532-nm LBO-based system also has a beam that is better collimated than the KTP beam.

Several animal studies have been performed with the 120-W 532-nm laser. Lee *et al*. investigated the use of the 120-W laser in five male beagles [28]. PVP was performed in antegrade fashion through a suprapubic cystotomy at 40, 80 and 120 W settings for three distinct firing periods (5, 10 and 20 s) at unique locations in the prostate. The 120-W HPS consistently vaporized more tissue per unit time, while the depth of coagulation (1.2–2.5 mm) was decreased compared to the lower powered systems. Kang *et al*. compared the use of the 120-W HPS laser to the 80-W HPS laser and the 80-W KTP laser in 96 specimens of bovine prostate tissue [29]. The 120-W HPS laser vaporized bovine prostate tissue more efficiently than the 80-W KTP laser and coagulation was equivalent. Lee *et al.* advised caution with the higher power setting, especially at 120 W due to the potential higher risk of capsular perforation and bladder wall perforation. Additionally, it is observed that higher power provides more efficient vaporization with less hemostasis, and as a result, utilization of the lower power coagulation setting is important in achieving hemostasis.

Heinrich *et al*. used blood-perfused porcine kidneys to determine the ablation capacity, hemostatic properties, and coagulation depth of a 120-W 532-nm laser compared to an 80 W laser [30]. The 120-W LBO laser offered a significantly higher tissue ablation capacity compared with the conventional 80 W KTP laser. The increased efficacy of the 120 W laser device was accompanied by a higher bleeding rate and a slightly deeper coagulation zone.

Few studies have been published on the safety and efficacy of the 120 W 532 nm laser prostatectomy in humans [31]. In a multicenter prospective study, 305 patients with BPH underwent laser prostatectomy with the 120 W HPS laser. Increases in maximum flow rate (Qmax) and decreases in postvoid residual urine, International Prostate Symptom Score, and prostate volume from baseline to follow-up were significant ($P < .001$) in all patients. A subgroup analysis was done in three groups of patients: those in retention (n = 63), on anticoagulation (n = 67), and with prostates ≥ 80 mL (n = 52). Complications were comparatively low in all groups.

In another study by Al-Ansari *et al*. randomized 120 patients with BPH to TURP or 120 W 532 nm laser [32]. A total of 55 and 54 patients completed 36 months of follow-up in the TURP and 532-nm laser groups, respectively. Baseline characteristics were comparable. Mean operative time was significantly shorter for TURP. Compared to preoperative values, there was significant reduction in hemoglobin and serum sodium levels at the end of TURP only. In the PVP, no major intraoperative complications were recorded and none of the patients required blood transfusion. Among TURP patients, 12 (20%) required transfusion, three (5%) developed TUR syndrome, and capsule perforation was observed in 10 patients. There was dramatic improvement in Qmax, IPSS, and PVP compared with preoperative values and the degree of improvement was comparable in both groups at all time points of follow-up. Storage bladder symptoms were significantly higher in PVP. A redo procedure was required in one TURP patient and six PVP patients ($P < .05$). Two TURP patients and four PVP patients developed bladder neck contracture ($P > .05$), treated by bladder neck incision; none in either group experienced urethral stricture or urinary incontinence.

Future of the 532-nm laser

The most recent advance is the Food and Drug Administration (FDA) approval of a 532-nm LBO-based laser system, capable of 180 W, with a feedback mechanism to control energy exiting the fiber (GreenLight XPS™; American Medical Systems, Minnetonka, MI, USA) system and a new water-cooled redesign high-power fiber (MoXy™ Fiber; American Medical Systems). The modifications in this system innovatively increase the safety and efficacy of this laser prostatectomy.

One aspect that predisposes a fiber to degradation, resulting in less collimation and deflection of the laser pathway, is heating at the tip of the fiber, probably caused by contact with tissue or adherence of tissue to the tip acting as a heat sink. The infrared-based feedback mechanism provides an automatic safety system; it monitors the heat generated at the fiber tip and if overheating is detected, which could cause fiber damage or failure, it briefly disables the beam to allow cooling and maintenance of a safe temperature. The system detects the infrared light emitted by all heated bodies to determine the temperature of the tip of the fiber. If excessive temperatures are reached, i.e. the fiber tip is embedded with excessive tissue contact, or excessive adherent tissue, or prostatic stones are encountered, etc., the laser emission is stopped momentarily. This will continue to occur as long as the source of the excessive heat is present.

Another new modification is applied to the coagulation power mode. The new 180-W capable system delivers the lower power coagulation mode laser light in intermittent pulses. This intermittent laser pulse modality mimics the intermittent delivery of power in electrocautery coagulation for hemostasis. However, the more important utility is the ability to better utilize the fiber for contact coagulation of arterial bleeders. With intermittent pulses, laser coagulation heat on tissue contact is limited by the intermittent pulsing and continuous flow of room temperature irrigant over the tip.

Finally, to improve the rate of vaporization efficiency, the power of the 180-W capable system was increased. The original 120-W system was rated at 120 W and the new system has a maximal power output of 180 W. To allow utilization of the 180-W capable system, while maintaining the same power density characteristic of the 120-W system and its fiber, a new fiber design was necessary. This new fiber has a wider diameter (750 µm vs 600 µm), which provides a wider and more efficient tissue vaporization effect.. This increase in fiber diameter of 0.15 mm increases the beam area by 50%. In addition, the end cap of the fiber has been redesigned to limit stray beams during the procedure. Most importantly, the cap is actively cooled with by room temperature normal saline flowing through the fiber at 1 mL/s and exiting at the beam point. This cooling feature also helps to protect the fiber from degradation, and only minimally reduces the amount of light delivered to tissue over the course of a long laser procedure.

All these modifications reduce fiber devitrification, the process by which the glass at the tip of the fiber becomes opaque, which then leads to power degradation during the procedure. Additionally, the continuous aqueous flow, metal cap, and feedback feature limit the build up of coagulated tissue on the tip of the fiber, which is one of the main causes of fiber failures. With these features, one fiber may be all that is needed for the treatment of most large prostates.

In our experience, we have found the 180-W laser with the actively cooled fiber to be extremely efficient. With the standard nonaqueous cooled fibers at 120 W, consistent efficiency is obtained to about 150 000 J. With the new aqueous cooled fibers and the 180-W laser system, power to 180 W can be utilized. However, at 120 W or greater, higher efficiency is obtained at the expense of hemostasis during the case. Especially at settings above 120 W, there is rapid vaporization of tissue while coagulation is decreased. This increased power and efficiency leads to a concern that if there were a misfire within the bladder at settings such as 180 W, damage to the bladder, including perforation, ureteral orifices, etc., could occur very quickly and without recognition by the surgeon. The actively cooled fiber predisposes to a reduction in the number of mechanical failures and in most cases only one fiber was required during treatment.

Patient preparation

There is minimal patient preparation prior to laser prostatectomy. Many patients today are routinely taking Aspirin, nonsteroidal anti-inflammatory drugs (NSAIDs), and other medications that may affect platelet function. Others may be actively receiving chronic anticoagulation with agents such as coumadin. Although these patients may have raised concerns in the era of electrocautery TURP, the hemostasis associated with laser prostatectomy allows select patients to be treated without stopping or changing their medical regimen [20, 33, 34] . However, the risks of treatment on active anticoagulation therapy should be clearly stated to the patient, as the risk of bleeding will always be higher while on anticogulation medication than off it.

Age-appropriate patients should be screened with both digital rectal examination (DRE) and serum prostate-specific antigen (PSA) levels. Prostatic abnormalities may be evaluated with transrectal ultrasound and biopsy as indicated. Such screening is important in laser prostatectomy since pathology is not adequately sampled for histologic examination [35].

A minority of patients with bladder outlet obstruction due to BPH will present with active urinary tract infection or significant pyuria. This should be treated prior to laser prostatectomy, especially since potential coagulated, nonperfused, necrotic tissue can remain *in situ* postoperatively and may become seeded with bacteria in the presence of active infection. For the typical patient who presents with sterile urine, routine antibiotic prophylaxis is recommended prior to laser resection of the prostate.

The consent for laser prostatectomy is very similar to that obtained for other transurethral operations. Patients are informed that they will require an anesthetic, and of potential complications associated with any invasive urologic procedure, such as bleeding, urinary tract perforation, infection, urinary incontinence, erectile dysfunction, retrograde ejaculation, and urethral stricture or bladder neck contracture. Finally, the patient should be informed that remaining tissue can grow back, causing recurrent voiding symptoms, and that additional prostate surgery may be required.

Preoperative preparation

There is no special preparation for a laser prostatectomy. Standard patient positioning in the dorsal lithotomy position with sterile draping and cleansing preparation is used, as for routine cystoscopy or any other transurethral operation. A properly functioning laser source and compatible laser delivery fiber are required.

Laser safety should be of paramount importance in the operating room. Laser energy can cause significant thermal injury to human tissues, including irreversible retinal damage. All operating room personnel and the patient must wear proper eye protection. Operating room windows should be covered to prevent the inadvertent passage of stray laser light; doors should be appropriately marked to warn outside personnel that laser energy is in use. When the laser is not being actively used, and in particular when the fiber is removed from the cystoscope and the working end lies free on the operative field, the surgeon should remove their foot from over the laser pedal and nursing personnel should close the shutter on the laser machine to prevent accidental firing. Paper drapes can be easily ignited and patients burned with the beam.

Technique

Laser prostatectomy requires local, regional or systemic anesthesia due to the pain associated with acute laser burns to the prostatic urethra. Leach *et al*. have in addition described a transperineal injection technique using lidocaine and bupivacaine to achieve local prostatic and pudendal nerve blockade, which when combined with intravenous sedation may also provide adequate anesthesia to perform laser prostatectomy [36]. When utilizing injection anesthetic, it is important to be aware of the maximum dosage as overdosing may result in significant adverse events.

Cystourethroscopy is performed with a standard 21–26F cystoscope. However, laser prostatectomy requires the specialized continuous-flow cystoscopes that have been purpose designed for laser prostatectomy. If continuous flow irrigation is inadequate to provide a clear field of vision, a suprapubic catheter can be placed to provide continuous intraoperative irrigation flow as well as postoperative urinary drainage. Since clinically negligible fluid absorption occurs during laser prostatectomy, special irrigation solutions are not required; normal saline is relatively inexpensive, is the fluid of choice compared to osmolar solutions, and provides good visualization. Room temperature, as opposed to warmed, irrigation provides cooling for the laser delivery fiber, limiting thermal damage as well as prolonging the usable lifespan of fibers (see above). The irrigant is hung 30 cm above the bladder and allowed to flow under gravity. Suction irrigation to the outflow port should be avoided, as it is unnecessary and may increase the risk of inadvertent bladder perforation. The prostatic anatomy is carefully assessed and the prostatic urethral length from the bladder neck to the proximal aspect of the verumontanum is inspected. The laser fiber is then passed through the working port of the cystoscope and visualized in the prostatic urethra in preparation for beginning laser application.

Laser energy is directed at the locations along the prostatic urethra that are obstructed, such as medial, lateral and anterior lobe tissue. A systematic and aggressive approach to laser prostatectomy will ensure complete laser treatment of all obstructive tissue elements. Laser resection may begin with either the medial or lateral lobes, but should always begin proximally and continued distally, working away from the bladder neck and toward the verumontanum: after the proximal prostate near the bladder neck is opened by superficial tissue vaporization, there will be improved irrigation flow for the more distal laser treatment.

Laser energy may be applied in a continuous fashion over an area, barring excessive tissue resection (e.g. perforation). PVP, the technique described for 532-nm laser prostatectomy, is often described as “painting” systematically over the surface of the prostate until a TURP-like cavity is formed. However, a more correct description is “mowing the lawn,” since a systematic sweeping technique is utilized to remove tissue in layers. Additionally, the optimal distance from tissue is small, within one fiber cap in a noncontact technique. Excellent vaporization results in a stream of bubbles, which represent the steaming away or vaporization of tissue. The laser source is used first to vaporize the median lobe to the level of the trigone. Once a channel has been created that allows adequate irrigation, the lateral lobes are next vaporized. This is followed by apical vaporization. At the end of the PVP procedure, a cavity should be present where the adenoma once was. If bleeding is encountered during PVP, the laser setting is lowered to allow coagulation instead of vaporization and the target area is coagulated. Optimally, the fiber tip should be held just off the mucosal surface such that a clear plane of water stands between the tip and tissue; by moving the beak of the cystoscope close to the fiber tip, the scope can be used to hold tissue away from the tip in many instances. In addition, resecting proximal before distal prostate tissue aids in freeing tissue from the fiber. Finally, when all else fails and occlusive prostate tissue must remain in contact with the metal mirror during treatment, a very slight vibratory motion of the fiber tip, i.e. no more than 1–2 mm longitudinal oscillation, combined with good water flow can keep tissue from adhering to the metal fiber tip. For all fibers with a mirror reflecting mechanism, routine cleaning of the fiber is recommended. The build up of spattered particulate on the fiber surface during treatment can cause superheating with fiber degradation. Prophylactic cleaning between each laser application and ensuring adequate room temperature water flow throughout the duration of each individual laser application are the most important means of preserving fiber integrity.

Advanced technique

Once the basic technique is mastered, the 532-nm laser can be used to enucleate, vaporize, and resect tissue. This technique is referred to transurethral laser enucleation of the prostate (TLEP). The procedure allows pathology to be collected and analyzed, improves surgical debulking of obstructive prostate tissue, and increases tissue removal efficiency, shortening operative times. This advanced technique is essentially a hybrid between TURP and laser vaporization utilizing the 532-nm laser. The technique can be quickly learned by those with prior transurethral resection skills. However, there is a learning curve to transurethral navigation of complicated and long anatomy that is clearly related to experience of transurethral resection anatomy. Pathology is provided and resection/enucleation is very complete. An incision is made through the median lobe until the bladder neck fibers can be seen (Figure 128.1). Sweeping motions with the side-fire laser fiber ensure that a wide channel is made, which allows for strong flow of cooling irrigant. Incisions are made lateral to the median lobe while visualizing ureteral orifices to ensure their safety. The intervening tissue between the incisions is divided into smaller chips. Multiple vaporization–enucleation–incision cycles are made down to the fibers of the prostatic capsule. Intervening tissue is vaporized, incised, and pushed into the bladder. Apical tissue proximal to the verumontanum is carefully ablated with care to preserve the verumontanum.

Postoperative care

At the conclusion of laser prostatectomy, a urinary catheter is left in place to provide drainage. A suprapubic catheter may be left in place to facilitate early or repeated voiding trials if desired.

Many routinely discharge patients following complete recovery from anesthesia, making laser prostatectomy essentially an outpatient procedure. Catheter drainage to a urinary leg bag if necessary can be maintained and easily mastered by most patients. Patients should note that if they have a history of preoperative urinary retention or detrusor hypocontractility with a large preoperative residual urine volume, they may require longer catheterization times. Postoperative management with suprapubic catheter drainage in these individuals may be ideal to allow easy or repeated voiding trials if needed.

Following catheter removal, immediate improvement in voiding may not occur. This may be due to inefficient vaporization resulting in a greater degree of coagulation necrosis. In fact, patients may have little or no change in voiding during the first 1–2 weeks postoperatively and they may experience slightly worse symptoms while the treated prostatic transition zone sloughs. During this time, patients may note a cloudy, white appearance in the urine, caused by proteinaceous material from the dissolving prostate; others may note the passage of minute particulate matter in the urine. This phase of active tissue dissolution can be associated with symptoms of mild dysuria, which are usually relieved by NSAIDs as needed. Phenazopyridine (Pyridium) appears to be much less effective for this syndrome, but may also be used as needed. By 4–6 weeks following laser prostatectomy, most patients begin to note a significant improvement in their voiding pattern. Improvement will continue in most men for an additional 6–12 weeks and longer, until maximum voiding outcome is achieved. By 3 months, voiding outcomes are similar to those expected after electrocautery TURP. With the more efficient vaporization and limited coagulation necrosis with high-power 532-nm laser applications, improvement may occur as short as a few days to a week with minimal dysuria.

Because of the superior surgical hemostasis associated with laser prostatectomy, significant restrictions on physical activity are not as limiting, even in the immediate postoperative period. After catheter removal, sexual intercourse is allowed immediately if desired but recommended at about 1-month postoperatively. Patients should be warned of the possibility that the ejaculate may be temporarily dark or bloody. The most significant risk from activity is hematuria, which is usually clinically insignificant but can on occasion result in clot

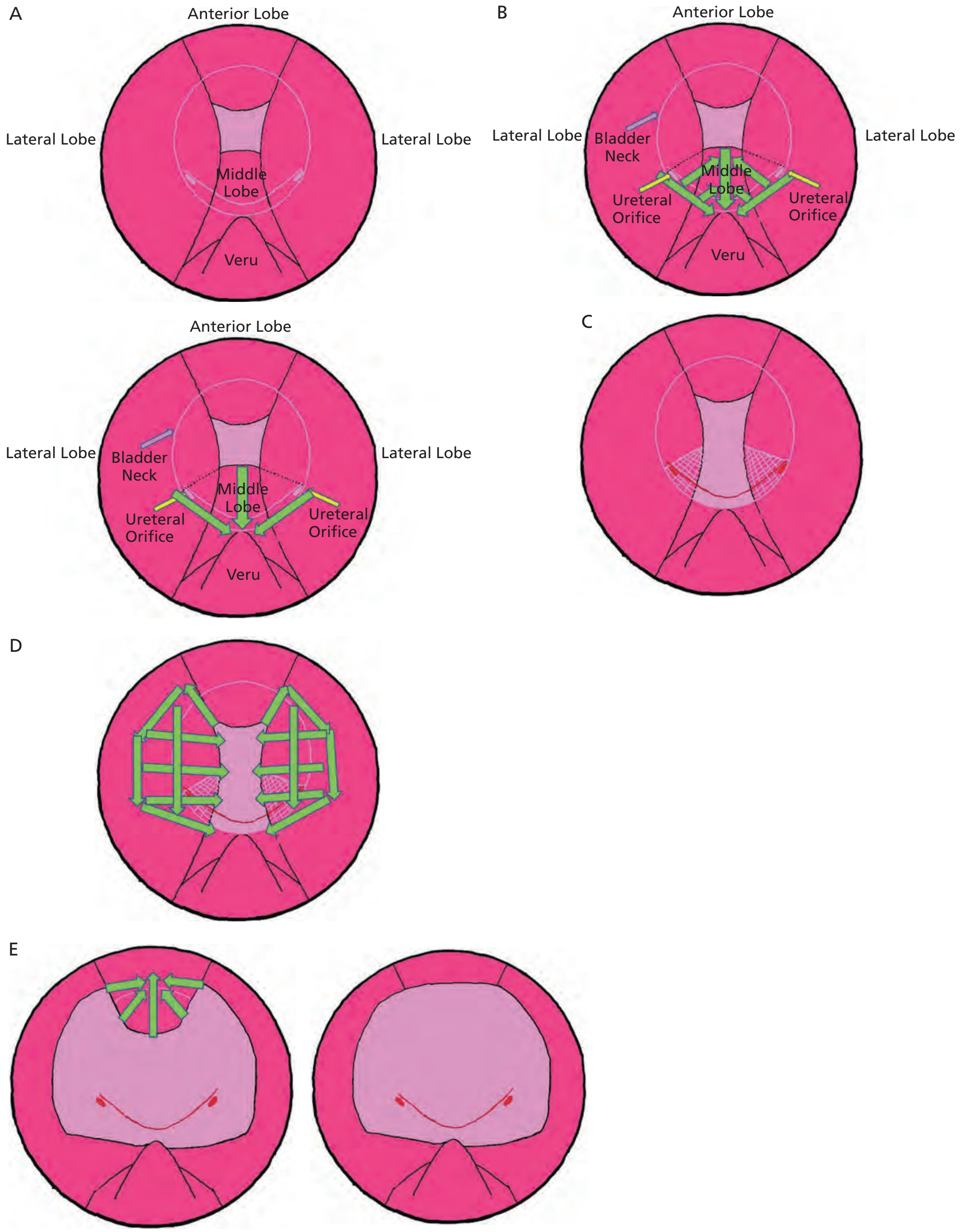
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Figure 128.1 Transurethral laser enucleation/vaporization technique as viewed through the cytoscope. (A) A wide incision is made through the median lobe until the bladder neck fibers can be seen. This channel should be wide enough to ensure a strong flow of cooling irrigant. Then, incisions are made lateral to the median lobe. It is important to visualize the ureteric orifices. (B) The intervening tissue between the incisions, if large, is divided into smaller chips. The chips are vaporized to reduce bulk before they are incised and placed into the bladder. (C) The median lobe is removed in this manner on both sides to view the ureteral orifices clearly from behind the bladder neck. (D) Multiple cycles of vaporization–enucleation–incisions are made, starting at the 11 o'clock position of the lateral lobe down to the fibers of the prostatic capsule. The 11 o'clock incision is continued medial to join the median lobe defect at the 7 o'clock position. Intervening tissue is vaporized, incised, and pushed into the bladder. The same procedure is done to the other side to remove the contralateral lateral lobe, starting at the 1 o'clock position to the 5 o'clock position. Apical tissue proximal to the verumontanum is carefully ablated with care to preserve the verumontanum. (E) Anterior tissue at the 12 o'clock position is then incised–vaporized–enucleated as needed to connect the 1 o'clock position to the 11 o'clock position. The goal is to achieve a transurethral resection (TURP)-like cavity with removal of tissue to the capsule and with a view of the ureteral orifice, as well as removal of any intravesical components. After resection is completed, the tissue chips are irrigated out with a combination of transurethral evacuators and graspers. With careful lasering of tissue to small chips, use of a morcellator is unnecessary.

retention requiring transient catheterization and irrigation.

Serum levels of PSA rise approximately 10-fold following laser prostatectomy, generally peaking on the first postoperative day [37, 38]. This seemingly corresponds with the height of capillary leakage and tissue edema after the laser burn injury. By 3 months, we have observed serum PSA levels to be at or below baseline in more than half of our patients. Approximately 90% have returned to or are below baseline values by 6 months. Those with significant and persistent elevations of PSA levels beyond this time probably should be evaluated for subclinical prostatic infection or occult carcinoma.

Complications

All reported studies have noted markedly less morbidity associated with laser prostatectomy compared with traditional surgical approaches. Bleeding is the main complication of traditional electrocautery TURP, often necessitating transfusion and causing associated problems such as clot retention, premature termination of the procedure, and inadequate relief of obstruction [39]. Bleeding can also result in continuous catheter irrigation and complications, such as stricture secondary to traction on the Foley catheter. Rarely, uncontrolled bleeding can even require open packing of the prostatic fossa. Poor visibility because of bleeding is also thought to be a cause of sphincteric damage and incontinence resulting from TURP. The incidence of hemorrhage requiring blood transfusion is 3.9% and this increases twofold if the amount of resected tissue exceeds 45 mL or if the resection time is longer than 90 min. In contrast to TURP, which cuts across the prostatic parenchyma and opens prostatic venous sinuses, laser prostatectomy seals blood vessels as it coagulates the transition zone and prevents both absorption of irrigating fluid and hemorrhage; the hemostasis associated with laser prostatectomy is thus superior, with even multiple studies of anticoagulated patients undergoing resection without bleeding complications [20, 40, 41].

Irrigant fluid absorption during electrocautery TURP results in a 2% incidence of TUR syndrome because of dilutional hyponatremia, glycine-induced ammonia intoxication or the direct toxic effect of glycine [39]. As with bleeding, fluid absorption increases with larger glands and longer resection times. Laser prostatectomy minimizes this complication, again through its sealing zone of coagulative effect on tissue which prevents fluid absorption.

The incidence of urethral stricture after electrocautery TURP is 3.1%; if bladder neck contractures are included, this figure approaches 5% [39]. Stricture formation is thought to be secondary to trauma induced by the large size of the resectoscope as well as the use of low-intensity, coagulating current, which penetrates deeper into tissue than cutting currents. Since laser procedures do not use electrical current, the cystoscopes utilized are smaller in size, and the overall operative time is usually shorter, the incidence of stricture is lower [42, 43]. The incidence of reoperation for residual obstructive tissue is difficult to determine since most published series of laser prostatectomy have documented initial experiences only with this technology. Our experience is that the incidence of strictures and bladder neck contracture is higher in patients with bladder dysfunction or bladder diverticulum, or following long procedures utilizing larger diameter scopes [44].

Postoperative infections may also occur after TURP. The incidence of urinary tract infection following TURP is 15.5% (median) while epididymitis occurs in 1.2% [39]. Urinary tract infections have been reported in 1–20% of patients following laser prostatectomy and epididymitis in 5–7% of patients [45–50] . The treatment of such infections may be more problematic in laser prostatectomies secondary to the residual necrotic prostate tissue that remains *in situ* for several weeks after laser coagulation. When this occurs, the most common manifestation is subacute prostatitis, characterized by significant and persistent irritative voiding symptoms, with mild prostatic and/or epididymal tenderness on examination, persistent pyuria, and positive urine cultures. Two cases of frank urosepsis have been reported following laser prostatectomy, both requiring TURP to remove infected necrotic prostate tissue [51]. Aggressive antibiotic therapy is therefore warranted in these patients.

Finally, retrograde ejaculation represents another potential side effect of electrocautery TURP, occurring in up to 90% of patients. Data with the 80-W KTP laser show that retrograde ejaculation also represents a potential problem in laser prostatectomy, with a 27% incidence of retrograde ejaculation [13]. The incidence of impotence following electrocautery TURP ranges from 4% to 13% [39], while its overall incidence following all forms of laser prostatectomy is rare. While data are limited, available 80-W KTP data show no loss of potency in patients treated with laser prostatectomy [13].

Contraindications

There are scenarios when laser coagulation of the prostate is not indicated, and where electrocautery resection may still be advantageous. These include certain cases of bladder cancer, in which acute electrocautery resection of the bladder neck or enlarged prostate may be necessary to access tumors behind the bladder neck, especially anteriorly. Rarely, this maneuver may also be needed for ureteroscopic access. In cases in which histologic assessment of the prostate for invasion by transitional cell carcinoma is required for staging of malignancy, electrocautery resection is indicated. Finally, in the uncommon case of chronic, recurring prostatitis where electroresection of the prostate may be used to remove infected tissue and/or prostatic calculi, laser prostatectomy cannot substitute for an aggressively performed TURP. In the rare case of a prostatic abscess that must be unroofed transurethrally, electrocautery resection is similarly indicated.

Conclusions

Laser prostatectomy has proved to be a safe and efficacious surgical intervention to relieve symptomatic bladder outlet obstruction. Overall morbidity contrasts favorably with standard surgical approaches. Moreover, laser technology is generally accessible to the practicing urologist. The transurethral endoscopic approach and operative techniques are not complex. These attributes have positioned laser prostatectomy as an accepted and often preferred surgical treatment of BPH.

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CHAPTER 129

Thulium Lasers

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Introduction

A good understanding of laser principles is required to choose the appropriate laser for any medical application [1, 2]. Important in this respect is the optimization of the absorption process of light in tissue, as laser radiation is simply directed light of a narrow bandwidth. This is synonymous with a single color and applies for all regions of the invisible and visible electromagnetic spectrum.

For surgical applications the most important process in the interaction of light and tissue interaction is absorption. When the laser beam hits tissue, a certain percentage is reflected by the boundary layer. The reflected radiation not only is lost for the surgical purpose but this laser energy, in the form of heat, may be a risk to surrounding tissue. Reflection depends on the optical properties of the tissue and the irrigant surrounding it, but is not very dependent on wavelength and therefore may be neglected when evaluating a laser wavelength for a surgical purpose. Since tissue is not homogenous, part of the incident laser beam is scattered, taking the applied laser beam out of its intended direction. The degree of scattering depends on the size of the particles that the laser beam encounters and on the wavelength of the laser. Shorter wavelengths are scattered to a much higher degree than longer wavelengths. Blue laser radiation is scattered more than green, green more than red, and red more than infrared. This scattered fraction of laser energy is not only lost for the intended purpose but may also cause unintended side effects.

In order to achieve absorption, a chromophore is required. Useful body chromophores for surgical procedures are melanin, blood, and water, although melanin has no use in urologic applications. The wavelength dependency of their absorption length is shown in Figure 129.1. The absorption length defines the optical pathway along which 63% of the incident laser energy is absorbed. Another concept, the extinction length, defines the depth at which 90% of the incident laser beam will have been absorbed and converted into heat.

With knowledge of the absorption process, it is easier to understand the laser–tissue interaction, both intended and unintended. When entering into an absorbing medium, the intensity of any laser beam decreases exponentially (Lambert–Beer's law). Absorbed laser energy is converted into heat and causes an increase in temperature. Depending on the density of absorbed heat, the impact on tissue may vary between coagulation and vaporization. The temperature in tissue increases with the density of heat per volume of tissue. This offers the opportunity for various surgical procedures, such as pure vaporization, vaporesection (in continuous wave lasers), or vapoenucleation when used for the treatment of benign prostatic hyperplasia (BPH).

The tissue effect is determined by the density of the absorbed laser power. The higher the absorption by a tissue is, the less heat is generated in its deeper layers. The understanding of this principle is important for any surgical laser application. At the same power level, a laser wavelength with a long absorption length may create a deep necrosis, whereas with a laser wavelength with a much shorter absorption length the absorbed laser power will be confined to a smaller volume which may lead to an increase of temperature above boiling

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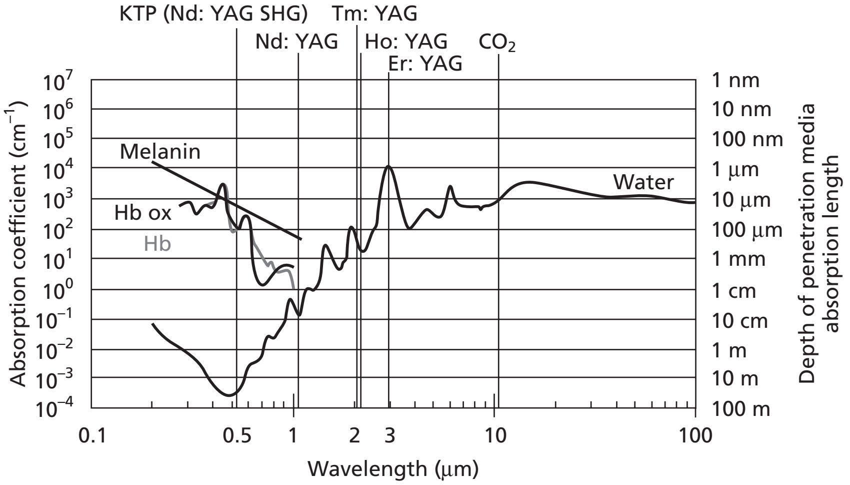

Figure 129.1 Absorption spectrum for melanin, hemoglobin (Hb; oxygenated haemoglobin, Hb ox), and water in comparison to selected laser wavelengths and carbon dioxide.

point and to immediate vaporization of tissue. The thulium (Tm):YAG lasers operate at a wavelength of 2013 nm and at this wavelength the absorption length is approximately 250 µm.

Pulsed and continuous wave lasers

Lasers can be divided in two major groups, pulsed lasers and continuous wave (cw) lasers. Holmium lasers are normally excited by flash lamps, which restricts the repetition rate due to heat accumulation in the laser crystal, whereas Tm:YAG lasers may operate in a cw-mode if excited by a laser diode. Pulsed holmium lasers create large pulsating steam bubbles in the irrigant surrounding the tip of the laser fiber, whereas those bubbles are much smaller for cw-mode lasers (Figure 129.2). For the holmium laser, the lifetime of a steam bubble corresponds to the duration of the laser pulse (~500 µs), which is too short to be visible in video transmission during endoscopic procedures.

The expanding steam bubble is used in holmium laser enucleation of the prostate (HoLEP) for the separation of the adenoma from the peripheral zone (see Chapter 127). Coagulation is achieved by the heat within the steam bubble. In contrast, the Tm:YAG laser constantly supports a steam bubble between the fiber tip and tissue. This bubble provides the optical contact for the laser radiation into the tissue. With fiber movement, precise cutting can be achieved. Due to its cw-mode and the absence of pulsating steam bubbles, cw Tm:YAG lasers allow smoother incisions in soft tissue, which is considered to be advantageous in urologic surgery.

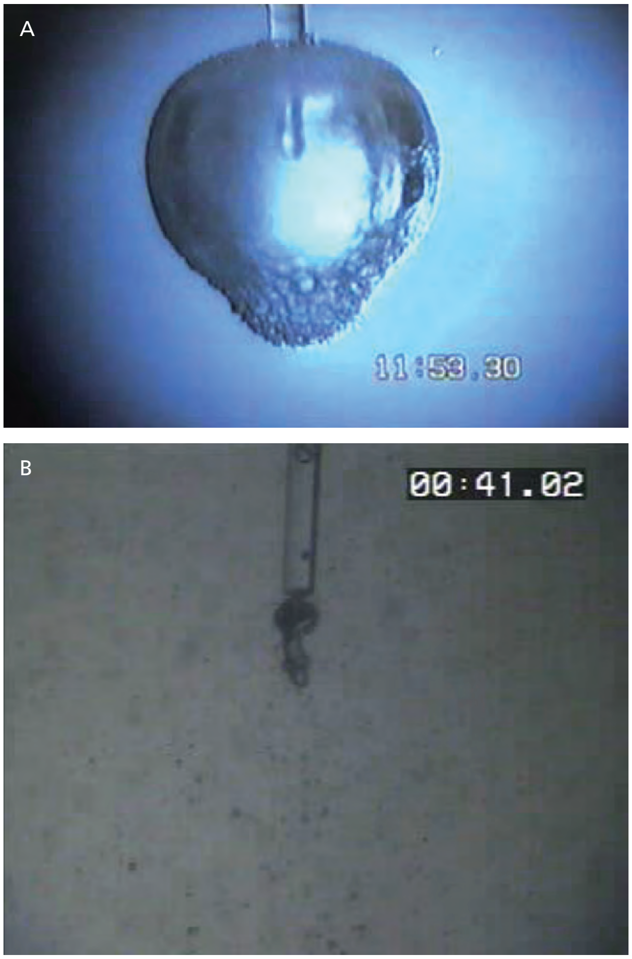

Figure 129.2 (A) Large steam bubbles in a pulsed laser (holmium laser; 2 J, 32 W). (B) Small steam bubbles in a continuous wave laser (2 µm, 50 W).

Accuracy, energy efficiency, and minimal collateral damage are all found with the cw-mode as opposed to the pulsed mode of the holmium laser.

However, the cw-mode is disadvantageous for the Tm:YAG laser's applicability for lithotripsy, since the required pulse peak mode for lithotripsy is not available in the cw mode of this laser [3].

Animal studies with thulium lasers

The first animal studies in the field of urology with Tm:YAG lasers were published in 2003. Theisen *et al.* demonstrated the tissue cutting ability of a Tm:YAG laser on pig liver, with coagulation zones of 0.8 mm or less [4]. El-Sherif and King tested the ablation abilities of thulium fiber lasers on various soft tissues *in vitro*, such as muscle, cartilage, and liver [5].

Fried reports on the vaporization of canine prostates *ex vivo* [6]. He used 88.5 ± 2.3 W of a 110-W high-power laser at a wavelength of 1.91 µm. Thus, his results may not be absolutely comparable with the commonly used Tm:YAG lasers working at 2013 nm, since absorption coefficient and penetration depth depend on wavelength and even small changes may have a relevant impact (see Figure 129.1). With the setting used by Fried, the laser works in both a cw and a chopped mode. The focus of his interest was measurement of the rate of tissue vaporization in a given time. This was 0.83 ± 0.11 g/min at 88.5-W laser power.

Thulium laser settings at 26 W, however, were not powerful enough to make efficient and accurate incision [7, 8]. The zone of thermal damage had a wide variance of 500–2000 µm. Fried stated that a higher power laser could be used to deliver more energy during a shorter pulse duration, with the intention to reduce the collateral tissue damage. Fried confirmed his original data in further *ex vivo* studies in canine prostates, and animal ureters and bladder neck tissue. He was not concerned about unacceptable collateral tissue damage, which was documented to be several hundred microns of thermally damaged tissue [7].

Whereas the first *ex vivo* studies were with soft tissue, Fried also published data on urinary stone fragmentation [9]. A cw high-power thulium fiber laser operating at a wavelength of 1.94 µm was modulated to operate in a pulsed mode with an output pulse energy of 1 J, 20-ms pulse duration, and repetition rate of 10 Hz. The fragmentation time to reduce various stones into particles of less than 2 mm was measured. In principle, high-power cw thulium fiber laser, when operated in pulsed mode, could fragment both soft and hard urinary stones, not accounting for the time this took.

Clinical experience with thulium laser treatment of the prostate

Clinically, thulium lasers were studied first in otolaryngology, pneumology, gynecology, gastroenterology, and neurosurgery [10–12]. An early paper in the field of urology dealing with the low-power vaporesection of BPH using a 50-W Tm:YAG laser was published in 2005 by Xia *et al.* [13]. Subsequently, laser treatment of the prostate has evolved as the main field for application of thulium lasers (Figure 129.3).

Vaporesection

Xia *et al.* reported on 30 patients resected using the so-called tangerine technique [13]. They sliced the prostate in tangerine-like pieces *in situ* and extracted these mechanically. This ability to cut was an important difference from the previously introduced lasers, especially the holmium:YAG (Ho:YAG) laser, which cannot cut or resect. Besides this, the application and surgical techniques of Tm:YAG lasers are very similar to those of the Ho:YAG lasers.

The 30 patients described in this first paper had a mean prostate volume of 58 mL, an average International Prostate Symptom Score (IPSS) of 19, and an average maximum urinary flow rate (Qmax) of 8.0 mL/s. The power used was 50 W. With a mean operating time of 56 min, tissue was removed at an average of around 1 g/min. This is in the range of Ho:YAG lasers, which enucleate at a rate of up to 0.71 g/min [14]. In Xia *et al.*'s first series, no significant bleeding was found during operation. No postoperative bladder irrigation was necessary. The Foley catheter remained *in situ* for 1–3 days. Blood samples before, directly after, as well as 1 and 3 months after the procedure did not reveal any changes. Three months after the operation, Qmax was 24.7 mL/s and IPSS 7.1. No cases of new onset of impotence were found. These data were confirmed at 1-year follow-up [15].

In 2007 Bach *et al.* reported their initial results for 54 patients after 70-W high-power vaporesection of the prostate (mean volume 30.3 mL) with the Tm:YAG laser and 1-year follow-up [16]. At that time, laser enucleation of the prostate with this laser had already been described [17], and a noted disadvantage of this procedure was the difficulty in removing the tissue from the bladder. Either a morcellator could be used or the so-called mushroom technique used [18]. In the latter, the prostate is left attached by a pedicle at the bladder neck and the tissue resected with a mono- or bipolar loop. Vaporesection is a protocol where small chips are produced with a Tm:YAG laser and washed out, similarly to the standard resection technique. In Bach *et al.*'s patients, Qmax was 8.1 mL/s, after exclusion of 14 patients with an acute

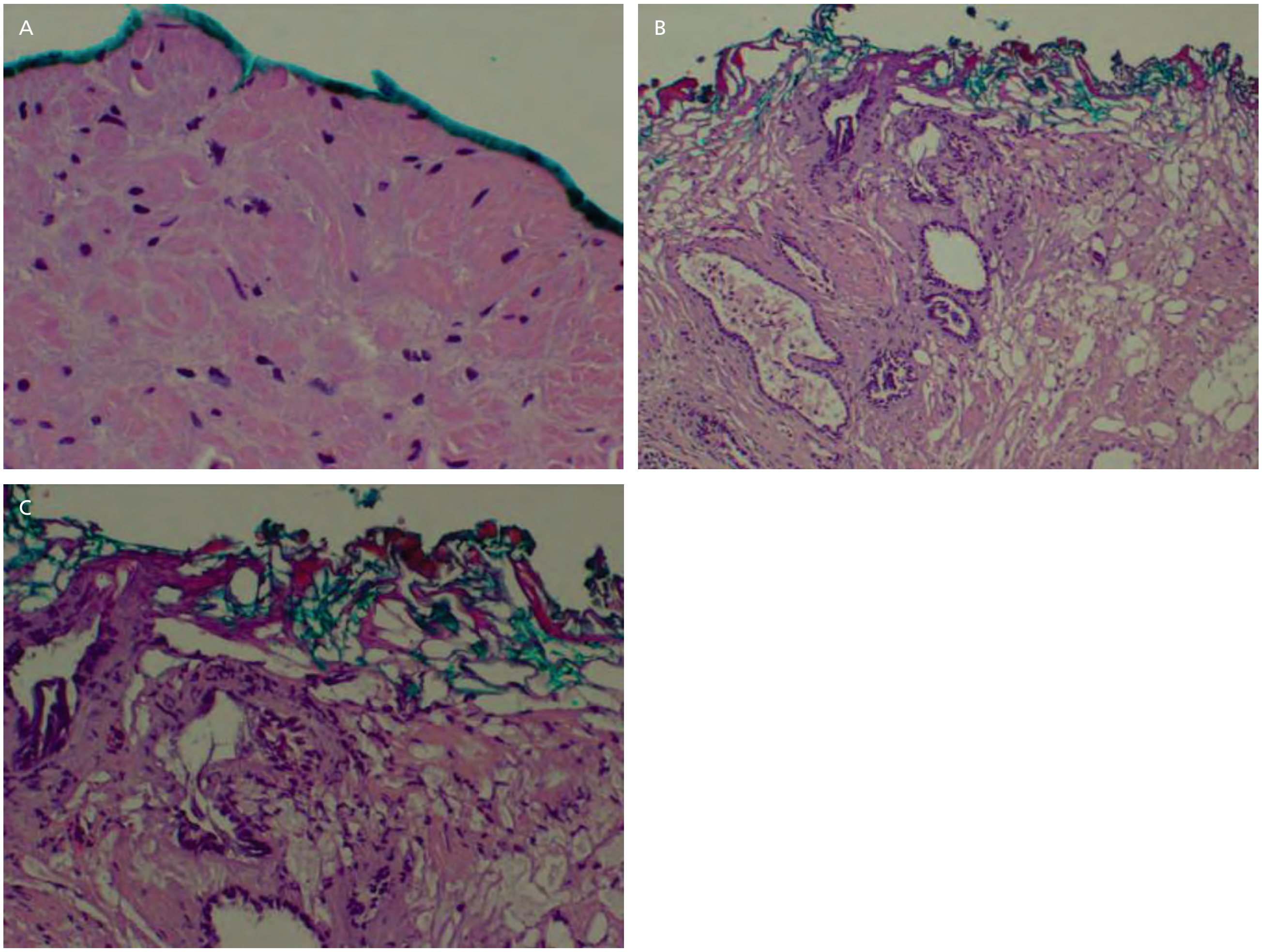

Figure 129.3 Human prostate following treatment with a 70-W, 365-µm fiber, thulium laser in contact mode. (A) Magnification ×20; (B) ×40; (C) ×100.

urinary retention. In these first results, removal of 0.6 g/min was achieved, which increased with experience to 1.5 g/min. Mean catheter time was 1.7 days (1–3 days). Transfusion was not required in any patient. However, six patients showed urinary tract infection with irritative voiding symptoms 1–2 weeks postoperatively, which required antibiotic therapy. After 1 year, no bladder neck stricture or urethral stenosis had occurred. These results were confirmed in the 18-months follow-up of the same group of patients [19].

After these reports from clinical practice, a systematic *ex vivo* evaluation of the thulium laser was performed by Wendt-Nordahl *et al.* [20]. The ablation capacity as well as the hemostatic properties were tested at different power settings in a previously used model of the isolated blood-perfused porcine kidney. Histologic examination of the ablated tissue followed. These results were compared to transurethral resection of the prostate (TURP) and treatment with the 80-W KTP laser. At a power setting of 70 W, the thulium laser displayed a higher tissue ablation rate, of an average of 6.56 g in 10 min. This is of course far more than achieved in clinical practice, since no time is lost for surgical orientation. The KTP laser ablated of 3.99 g of tissue in the same time, whereas with TURP 8.28 g was removed in 30 s. The bleeding rates were 0.16, 0.21, and 20.14 g/min, respectively. The corresponding depths of the coagulation zones were 264, 666.9, and 287 µm, respectively. In conclusion, this study shows that the thulium laser offers a higher tissue ablation capacity and similar hemostatic properties to those of the KTP laser, and in comparison to TURP the bleeding rate was significantly reduced. The smaller quantity of removed tissue as compared to TURP reflects the fact that the thulium laser was used for vaporization only.

The first randomized prospective study was performed by Xia *et al.* [21]. They compared the thulium laser and TURP in clinical practice. Xia *et al.* randomized 100 patients into two groups: 52 underwent laser resection using the tangerine technique mentioned above, and 48 standard TURP. Preoperative assessment included IPSS, International Index of Erectile Function (IIEF), and urodynamic studies. Those parameters were re-evaluated at 1, 6, and 12 months. Catheterization time was significantly shorter in the laser group (45.7 vs 84 h; $P < .0001$). Blood loss was less in the laser group with a decrease in hemoglobin of 0.92 g/mL vs 1.46 g/mL ($P < .001$) in the TURP group. IPSS and IIEF as well as urodynamic studies did not reveal any significant difference between the groups. Both groups benefitted from the respective interventions.

Results from a larger series of patients (n = 200), also with larger prostate sizes (up to 120 g), were published by Mattioli *et al.* [22]. They used a 70-W laser with both bare-ended and side-firing laser fibers. Bare-ended fibers used with the cw thulium laser are applicable for all BPH protocols, such as vaporization, vaporesection, and vapoenucleation; however, side-firing fibers are used for vaporization only. Mattioli *et al*. advocated the use of both fibers They used a laser that enabled switching with a foot pedal between the two modes, and preferred to resect first and vaporize thereafter. In patients with prostates smaller than 35 g, vaporization was performed; in those with prostates larger than 35 g vaporesection and/or vaporization was performed. Mean catheterization time was 16 h (range 12–72 h). The efficacy of the procedures was evaluated with uroflowmetry, postvoid residual volume (PVR), and evaluation of the symptoms with the IPSS questionnaire. The authors concluded that the clinical outcome was comparable with TURP and the KTP and Ho:YAG lasers.

Szlauer *et al.* have published a DVD on the vaporesection procedure with a thulium laser [23]. This shows the main steps of the technique as introduced by Bach *et al.* [16]. The laser fiber is moved semi-circumferentially from the verumontanum towards the bladder neck, thereby undermining tissue and cutting chips. Szlauer *et al.* reported on the evaluation of 56 nonconsecutive patients. The mean procedure time was 60 min, postoperative irrigation was necessary in 19 of 56 patients (29%), and the mean time of catheterization was 23 h. The decrease of hemoglobin was low at 0.2 mg/mL until the day of discharge. Average Qmax improved from 8.1 to 19.3 mL/s ($P < .001$), and the PVR decreased from 152 to 57 mL ($P < 0.05$). This study included the first report of the need for blood transfusion (2 patients, 3.6%) after thulium laser procedures. Two patients needed recatheterization postoperatively. After a mean follow-up of 9 months, IPSS improved from 19.8 at baseline to 8.6 ($P < .001$). During the learning curve, persisting obstructive symptoms in four patients necessitated a second procedure. Szlauer *et al.* chose TURP, while a few other authors have reported satisfactory second procedures for persisting complaints utilizing the Tm:YAG laser in a resection technique [24]. During the learning curve of a new technique, such as any laser procedure, it is appropriate to fall back on the standard procedure. Two patients in this series developed postoperative complications (one urethral stricture and one bladder neck contracture).

Vapoenucleation

Following their work on vaporesection with thulium lasers, Bach *et al*. followed the path of holmium laser enucleation and implemented thulium lasers for this technique (vapoenucleation of the prostate) in 2009 [24]. This represented a development, because vaporesection and indeed any kind of pure Vaporization was limited to smaller glands, as the amount of tissue that can be removed by vaporization techniques is time limited, necessitating prolonged operating times with increasing prostate volume. It became obvious that for larger glands, morcellation must be an integral part of the procedure. Bach *et al*. again used a 70-W laser to remove the tissue, similarly to the previously described three-lobe technique in HoLEP [25], in 88 patients with a mean prostate size of 61.3 g. In brief, the procedure starts with the marking of the distal resection border close to the apex of the prostate. Next, two Turner–Warwick-like incisions down to the surgical capsule are made at the 5 and 7 o'clock positions up to the previously marked distal resection border. Then, the entire median lobe of the prostate is enucleated. After that, the first lateral lobe and consequently the second lateral lobe are enucleated and positioned into the bladder for morcellation. The procedure is carried out with normal saline as the irrigant. After enucleation, tissue is morcellated within the bladder.

In this study, Bach *et al*. showed that the thulium laser could be used for enucleation of prostates, as previously shown with Ho:YAG lasers. The authors discussed the advantages of this laser in comparison to open simple prostatectomy and Ho:YAG laser enucleation [25]. They reported that both intra- and post-operative course were improved. The operative time was 72 min, of which laser time (beam on) was 32.4 min. The remainder of the operative time, as in any other transurethral procedure, was taken up by instrumentation, catheterization, and morcellation. According to the authors, a suprapubic trocar could be used to perform a low-pressure procedure. An average of 127 kJ of laser energy was applied. An average of 31.7 g of prostatic tissue was available for histologic examination. The percentage of tissue lost through vaporization was estimated to be 30%, and it should be noted that the amount of retrieved tissue is often underestimated due to this fact. The average Foley catheter time was the same as in other laser procedures, being 2.1 days. Three patients (4.2%) had a high residual urine after removal of the Foley catheter and were discharged with the suprapubic catheter *in situ*. At 1-year follow-up, improvements in urodynamic parameters appeared to be durable, with an increase in Qmax from 3.5 to 23.3 mL/s ($P < .001$) and decrease in PVR from 121 to 33 mL. IPSS decreased from 18.4 to 6.8. Early complications were urinary tract infection in 6.8%, hematuria in 5.6%, and need for immediate retreatment in 2.2%. One patient developed a urethral stricture. Postoperative dysuria was reported in 27%, a rate similar to that with any other ablative procedure in the prostate [26].

Open simple prostatectomy is considered the standard technique for large glands. It is effective and durable, but the severe complication rate is high. In one of the last large series of open prostatectomy, Serretta *et al.* in 2002 reported a complication rate of 15% [27]. Although the average overall complication rates for open prostatectomy and Tm:YAG laser prostatectomy appear to be comparable, the rate of severe unexpected complications, especially bleeding-related complications and transfusion rates, drop significantly with Tm:YAG laser prostatectomy. This is particularly important because surgical treatment for BPH tends to be performed in an older age group. Transfusion rates of 8.2–26.5% have been reported with open prostatectomy [28], in contrast to rates of around 1% in a large Tm:YAG series [29]. Infection occurred in 8.6% of open prostatectomies.

To overcome this problem with open prostatectomy, HoLEP was introduced for the treatment of all sizes of prostate [17]. The rate of blood transfusion is lower with this technique; reported at only 1.3% by Elzayat and Elhilali [30]. To overcome some disadvantages of the Ho:YAG laser, thulium lasers are now used for the same indication and using the same technique. The main advantage of the thulium laser is its cw-mode that allows clear cuts and therefore better vision of the surgical site. The incision in the tissue is clear and the penetration is shallow. Thus, the surgeon can cut at any desired point and is not dependent on finding the exact layer of the surgical capsule between the adenoma and peripheral zone. In case of losing this path it may be easier to return to the preferred layer using the thulium laser. For those in the early stages of learning the enucleation protocol, this may be a major problem with any other kind of laser. Clear cuts with a thulium laser therefore lead to a shorter learning curve [31].

The results of long-term follow-up for HoLEP, being the earlier introduced technique, are now available [32], but there is no reason to presume that outcomes for thulium laser enucleation will differ. Thus, thulium laser enucleation appears to be repeating the experience with Ho:YAG lasers, but with an improvement in the ability to resect and consequently a shorter learning curve. With both thulium and Ho:YAG laser enucleation (HoLEP) of the prostate, simple open prostatectomy becomes obsolete.

At this stage, three surgical protocols using thulium lasers for the treatment of BPH have been introduced: vaporization, vaporesection, and vapoenucleation. The following discussion considers subgroups of patients, cost, and recent developments in the standard protocols.

Patient subgroups

Bach *et al.* evaluated the feasibility and efficacy of thulium laser enucleation of the prostate in 65 patients with an indwelling transurethral catheter due to recurrent urinary retention secondary to BPH [33]. They were compared to 143 patients scheduled for the same procedure, but without catheterization for urinary retention. Both groups were comparable in terms of clinical parameters. On the day of discharge, the mean Qmax had improved in both groups ($P = .771$) and the PVR was similar ($P = .176$). The incidence of bleeding was similar, but urinary tract infections (UTIs) were more frequent in the catheterized group. Since up to 40% of patients scheduled for surgery for BPH can develop acute urinary retention, this study has important impact on the decision as to what intervention to perform. Compared to other laser techniques treating similar groups of patients, the thulium laser appears to offer advantages [34].

Cost

The high initial costs and prolonged learning curve are considered disadvantages of the introduction of laser techniques. As mentioned above, the learning curve with thulium lasers seems to be shorter than for other laser treatments. As far as economics are concerned, Varshney and Agrawal have argued that the lower blood loss, shorter catheter time, and decreased hospital stay offset the high initial expenditure of laser treatment, making laser treatment an attractive option even in the developing world [35]. In addition, lasers can be used in high-risk surgical patients. Especially in cardiac patients transurethral resection syndrome is not an issue, because normal saline is used as the irrigant and absorption is negligible. Patients on anticoagulation can be treated due to the superior hemostatic capabilities.

Recent developments and modifications to the standard procedure

Early studies with thulium lasers were performed with a 70-W laser, but pushed by developments in other laser systems, a 120-W thulium laser has been introduced and it has been necessary to reassess the ablative and hemostatic properties [36]. In particular, it has needed to be clarified if the higher power would create a deeper zone of tissue coagulation and tissue penetration, which might lead to an increased risk of collateral damage. Bach *et al.* recently showed that the amount of tissue ablation increased with increased output power, but with increasing fiber diameter (800-µm fiber instead of 550 µm), the depth of the cut decreased. As shown in their previous study [20], tissue ablation with the thulium laser appeared to be more effective than reported for other systems. The recent study indicated also that the bleeding rate did not increase with the higher power output. In contradiction to that, the same group has shown that bleeding rates increase at higher power settings [36, 37].

A more interesting consideration with the higher power laser is the effect to deeper tissue layers, leading to a lower possibility of histologic assessment or even collateral damage. Using standard H&E staining, the extent of the coagulation zone with the 70-W thulium laser is reported to be 0.36 mm with the 550-µm bare-ended fiber and 0.49 mm with the 800 µm fiber [35], smaller than reported for other laser systems [38]. Deep tissue penetration is responsible for obstructive necrotic tissue, thus leading to a high reoperation rate [39]. The dissipation of heat does not end at the border of the coagulation zone. For the thulium laser, higher output power does not appear to compromise clinical results.

To overcome any compromising side effects due to penetration depth, Herrmann *et al.* have modified the prostate enucleation procedure [40]. Laser power of 90 W is used only for the incision at the verumontanum and bladder neck for removal of the middle lobe. Then, 30 W is used for coagulation of small vessels crossing the surgical capsule. The lobes themselves are liberated by blunt dissection. The rate of postoperative dysuria with this technique will be of particular interest, but clinical results are not yet available.

There have been two recent reviews of the laser treatment of prostates, including thulium lasers. Herrmann *et al.* included articles published between 1995 and 2009, and encompassing 3669 patients [41], and concluded that most contemporary laser treatments modalities provide similar Qmax improvement compared to surgical treatment. To differentiate one treatment from another, they advocated comparative computer urodynamic investigations.

Rieken *et al.* used a Medline search covering the years 2006–2009 [29]. They focused on safety, and intra- and post-operative morbidity. Best data are available for Ho:YAG laser enucleation with two meta-analyses. Photoselective vaporization of the prostate (PVP), GreenLight [potassium titanyl phosphate (KTP) or lithium borate (LBO)] is characterized by excellent hemostatic properties in patients with or without oral anticoagulation, but long-term results show a reoperation rate comparable to TURP. Thulium lasers show low intra- and post-operative morbidity, but data are limited and initial results need to be confirmed in large-scale trials [42].

Bach invited all authors of scientific thulium laser publications to define the terminology for different surgical techniques, and he proposed the use of this terminology to ensure a homogenous nomenclature [43]. In brief, the authors recommended the following terms: ThuVaP for vaporization of the prostate, ThuVaRP for resection, ThuVEP for enucleation in combination with vaporization, and ThuLEP for blunt enucleation with laser support, respectively (see Table 129.1).

Thulium lasers in the treatment of urinary tract conditions

There is less experience of the use of thulium lasers in the treatment of strictures and transitional cell carcinoma (TCC) of the upper and lower urinary tract.

Bladder neck contractures

Bach *et al.* reported on the treatment of bladder neck contractures in 14 patients using a 70 W 2 µm cw laser [44]. The unsatisfactory results with other interventions,

Table 129.1 Proposed nomenclature for thulium laser protocols (from Rieken *et al.* [41], with permission).

	Basic principle	Consensus nomenclature
Vaporization	Destruction	Tm:YAG vaporization of the prostate (ThuVaP)
Vaporesection	Resection into small tissue chips (to be washed out)	Tm:YAG vaporesection of the prostate (ThuVaRP)
Vapoenucleation	Enucleation in combination with vaporization of the median and lateral lobe	Tm:YAG vapoenucleation of the prostate (ThVEP)
ThuLEP	Blunt enucleation with laser support	Tm:YAG laser enucleation of the prostate (ThuLEP)

such as bladder neck incision either by cold knife or electrocautery, stents, or balloons, lead them to try thulium lasers. The use of lasers for the treatment of strictures was not new, but due to their operational mode and disadvantageous wavelength, they were of limited use; the coagulation zone was suspected of causing recurrent strictures. The technical features and biologic effect of thulium lasers make them more appealing for the treatment of strictures. It should be remembered that the thulium laser can cut through any kind of tissue, no matter whether perfused or scarred. Bladder neck incision also offers a good way to learn the handling of thulium lasers, as the procedure is short, bleeding does not occur, and orientation *in situ* is clear.

In Bach *et al*.'s study, bladder neck incision was carried out successfully in all patients [44]. Mean operative time and catheter time were short: 7 min and 6.5 h on average, respectively. The Qmax improved from 9 to 25 mL/s after 2 months and 23 mL/s after 12 months, while the American Urological Association (AUA) symptom score improved from 22 to 8. Two patients developed restenosis during that time.

In a much larger series of 238 patients [45], Guo *et al.* confirmed the positive results of Bach *et al.* There were no complications such as significant blood loss, urine leakage, or rectum injury. Qmax increased from 3.2 mL/s preoperatively to 16.7, 18.7, and 19.2 mL/s directly after removal of the catheter, and 3 and 5 months after the intervention, respectively. IPSS improved from 28.3 to 7.1 to 5.3, respectively. Forty-three patients developed restenosis and seven were incontinent 1–3 weeks after catheter removal. All cases of incontinence were temporary.

Ureteral strictures

Thulium lasers have been used in a completely new technique for the treatment of subtotal ureteral strictures [46]. Using a combination of endourology and fluoroscopy, the laser fiber is pulled through the stenosis "blindly." In these extreme cases of strictures, the restenosis rate was as high as 38.8%, although the rest of the group was spared from major surgical intervention. Thus, while the results of thulium laser intervention for this application are practicable, they are not superior to any other procedure.

Transitional cell carcinoma

Endoscopic management of upper urinary TCC has assumed an important role in diagnosis and treatment [47]. The well-known disadvantages of laser treatment also became obvious in the treatment of this entity; either the depth of penetration depth was too great or the pulsed mode disrupted the tissue to be treated. Consequently, Scoffone *et al*. suggested thulium lasers as an option in this type of procedure [48].

Gao *et al.* has reported the use of thulium lasers for the treatment of recurrent bladder tumors [49] a condition for which transurethral resection of the bladder (TURB) is considered to be the standard procedure. According to the authors, histology may not necessarily be required in these cases. They performed thulium laser resection of bladder tumors (ThuRBT) via flexible cystoscope in 32 patients. All patients were treated successfully with no hemorrhage, obturator nerve reflex or vesicle perforation. Biopsies taken after the procedure revealed no residual tumors. During the first year of follow-up, local and heterotopic recurrences were found in three and six patients, respectively. The accumulated recurrence rates at 3, 6, and 12 months were 9%, 22%, and 28%, respectively. In conclusion, this first report on treatment of recurrent superficial bladder cancer via flexible cystoscope appears to be promising. Furthermore, it can be performed as an outpatient procedure.

Other transurethral procedures

There has been recent interest in the use of thulium lasers in other than transurethral procedures, due to their shallow depth of penetration and good coagulation abilities. Mattioli *et al.* reported on their initial experience with partial nephrectomy, either open or laparoscopically, in nine patients [50]. In six patients, the big vessels were clamped, while in three they were not. Mean tumor size was 3.5 cm and mean operative time was 135 min for the open procedure and 210 min for the laparoscopic procedure. Blood loss was 260 mL in the open procedure and 156 in the laparoscopic procedure. One case was done under renal hypothermia. The authors were able to outline the precise dissection as there was an absence of bubbles and minimal formation of gas during the laparoscopic procedure. The laser coagulated vessels up 1.6 mm, which allowed good sealing of the surface. Operation time was relatively short because suturing of renal parenchyma was not required. Gruschwitz *et al*. have also reported successful results for Tm:YAG laser-supported partial nephrectomy [51]. These observations are underlined by an animal study of partial nephrectomy using a natural orifice transluminal endoscopic surgery (NOTES) procedure [52]. Liang *et al.* have investigated *ex vivo* how to overcome the problem of smoke formation during laser procedures [53].

Conclusions

The development of laser technology from the cradle of modern physics in 1900 by Planck to its latest medical boundaries is an exciting example of how basic physics finds its way into clinical practice. Detailed knowledge of technical aspects has lead to great improvements in laser devices and consequently better medical treatment. Thulium lasers in this respect can be seen as a further development of Ho:YAG lasers. Its cw-mode leads to a faster learning curve, and consequently many benefits of Ho:YAG procedures can be brought to a larger community of users [54].

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CHAPTER 130

Interstitial Laser Therapy

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Introduction

Interstitial laser therapy of the prostate, also called interstitial laser coagulation (ILC) or laser-induced interstitial thermotherapy (LITT), was originally developed to generate coagulation necrosis of a large volume *inside* the adenomatous tissue of the prostate, without damaging the urethra and internal sphincter, to achieve a physiologic volume reduction of the obstructive prostate tissue by secondary atrophy rather than by tissue sloughing. After some years of clinical experience and growing knowledge on ILC and related techniques, such as transurethral needle ablation (TUNA), it became obvious that the laser energy that is administered by placing a laser radiation applicator inside tissues ("interstitial" laser application) can achieve different quantitative and qualitative effects, and in the case of treating benign prostatic hyperplasia (BPH) different clinical effects may occur. These depend not only on the type of laser source, laser applicator, and irradiation parameters, but also particularly on the "treatment scheme" (e.g. number of applicator placements) the surgeon is following. ILC is surgeon dependent. Therefore, interstitial laser therapy can be performed as a procedure in which a large tissue volume is coagulated with or without preserving the urethra, resulting in a significant volume reduction of the prostate and a TURP-like cavity. It can also be performed using the same laser, applicator, and irradiation parameters, but resulting in a low-volume coagulation. If the first type of interstitial laser therapy, "high-volume" ILC (HV-ILC) is performed, the surgeon may achieve a clinical effect comparable to transurethral resection of the prostate (TURP); in the second type, "low-volume" ILC (LV-ILC) or LITT, any clinical effects that may occur are probably unrelated to volume reduction or tissue ablation [1]. Unfortunately, the literature published to date does not discriminate between HV-ILC and LV-ILC, nor does it mention that ILC is a procedure whose clinical outcome depends highly on the surgeon. The terminology used in the past does not even reflect these differences.

If laser energy is administered by irradiating an outer or inner surface, e.g. in transurethral free-beam laser application such as visual laser ablation of the prostate (VLAP), the amount of tissue that can be necrotized is limited by two factors: the relatively shallow penetration depth of the laser radiation and the limited size of the organ surface that is accessible [2–4]. By contrast, in interstitial laser irradiation the applicator can be inserted into the desired tissue as deep and as often as necessary to coagulate any amount of tissue.

Clinical outcomes, namely symptomatic improvement, voiding parameter improvement, and complications, depend not only on surgical technique and strategy, but also on biologic action. For unknown and unforeseeable reasons in some individual cases, the necrotic tissue may remain in place, necessitating resection.

Indications

Patients selected for interstitial laser therapy have moderate-to-severe lower urinary tract symptoms (LUTS) and mild-to-moderate, or with HV-ILC even severe, bladder outlet obstruction (BOO) related to BPH, with moderate-to-pronounced benign prostatic enlarge-

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ment (BPE), and would otherwise be candidates for surgical intervention, either transurethral or open, or other minimally invasive or laser procedures. In principle, there is no limit to the prostate volume that can be treated by this approach; even large middle lobes can be treated [5]. Concomitant diseases, such as strictures of the urethra or bladder calculi, can be treated in the same session.

Patients with chronic urinary retention or poor detrusor function will need to have a catheter in place for a longer period after the procedure because of the time required for the prostate to shrink sufficiently to clear the obstruction. Of course, longer catheterization is necessary in any type of treatment in which there is no immediate tissue removal (secondary tissue ablation).

Virtually no intraoperative morbidity is associated with interstitial laser therapy and in principle it can be performed with the patient under local anesthesia (given that it appears acceptable to perform a cystoscopy with minor transurethral manipulation under local anesthesia) [6, 7]. Thus, even high-risk patients who are not candidates for transurethral resection need not be excluded from this treatment modality. Recurrent or residual BPH after previous prostate surgery, laser treatment, or microwave treatment can also be treated by ILC.

Although ILC alone is a sufficient treatment, in smaller prostates with median bar obstruction, an additional incision of the bladder neck may be useful [8, 9]. This can be done at the 5 and 7 o'clock or at the 6 o'clock positions using either a Collings knife or a bare laser fiber. Other combination treatments, such as ILC of the side lobes plus subtotal transurethral resection (e.g. of the median lobe), may be beneficial for selected patients to shorten postprocedure catheter time. An interesting concept might also be the combination of ILC and TURP, with ILC performed just before standard TURP in order to improve hemostasis. The combination of simultaneous interstitial laser therapy and VLAP may increase the efficacy of each procedure, but no major series have been published on this combination. The combination of ILC with temporary stents has been much discussed, but no major study has been reported on this either. A few reports have demonstrated the feasibility of interstitial laser ablation using the holmium (Ho):YAG laser [10–12].

Antegrade ejaculation was preserved in approximately 80% of patients who underwent the laser procedure [13–18]. This represents a significant improvement over TURP, but the risk of retrograde ejaculation after interstitial laser therapy cannot be eliminated completely.

Interstitial laser therapy should therefore be the first choice for high-risk patients who need surgical intervention and for patients who require surgical treatment but in whom it is essential to minimize surgical risks. Patients desiring rapid symptom relief after treatment should be excluded from laser coagulation therapy and preferably treated with TURP, laser vaporization or laser resection/enucleation [19].

Patients whose primary concern is normal ejaculation should be treated medically. If surgery for them is unavoidable, interstitial laser therapy is one treatment of choice and there is a very fair chance of preserving ejaculation. The surgeon can increase this chance by not treating the bladder neck; however, this carries the risk of a suboptimal correction of voiding symptoms. In any case, the patient should be advised that the loss of prograde ejaculation is a possible side effect of interstitial laser therapy.

Patients with obstructive symptoms from carcinoma of the prostate are also candidates for interstitial laser therapy [20]. The indications are the same as those for palliative transurethral resection to treat BOO, such as locally advanced disease. However, interstitial laser therapy is definitely not an alternative to radical prostatectomy or curative radiotherapy.

Patients with symptomatic BPH who are suspected of having prostate cancer because of their elevated serum prostate-specific antigen (PSA) level, but who are not candidates for curative treatment, can be treated with ILC, but they should have a biopsy of the prostate immediately after but during the same session as treatment. If curative therapy is possible, a screening biopsy should be performed and evaluated before laser treatment. If biopsy results are positive, the patient should not receive interstitial laser therapy.

Patients who have bladder cancer close to or at the bladder neck or in whom invasion of the prostate is uncertain should not receive interstitial laser therapy. The procedure is also contraindicated in cases of acute prostatitis or epididymitis and when there is an abscess of the prostate. Chronic prostatitis, however, which is frequently present in BPH patients, is not a contraindication to interstitial laser therapy.

Patient preparation

As in most minimally invasive modalities for the treatment of BPH, in interstitial laser therapy no tissue is sampled for pathologic examination. Therefore, a digital rectal examination and serum PSA level evaluation are essential. If either of these is suspicious of cancer, a transrectal ultrasound (TRUS) examination and a screening biopsy should be performed before or after interstitial laser therapy, depending on the patient's age and physiologic status, and the potential treatment consequences.

A patient with an active urinary tract infection (UTI) must be treated with appropriate antibiotics before interstitial laser therapy. Patients with acute epididymitis or acute prostatitis should not undergo interstitial laser therapy until they have completely recovered from these conditions. If there is significant postvoid residual urine volume (PVR) or if the patient has chronic or acute retention [21], a suprapubic or Foley catheter should be inserted and left in place after treatment until voiding is sufficient. Routine perioperative antibiotic prophylaxis is recommended [14] to produce sterile urine preoperatively, particularly if a prostate biopsy is to be performed transrectally at the time of laser therapy.

As in any other BPH treatment, the success of interstitial laser treatment should be monitored during follow-up. Therefore, the patient's American Urological Association (AUA) symptom score, maximum urinary flow rate (Qmax), PVR, and prostate volume should be measured before treatment. Additional urodynamic measures (pressure–flow studies) are helpful for assessing the decrease in obstruction after laser therapy.

The common diagnostic procedures usually required for TURP are sufficient for interstitial laser therapy. Special radiologic or endoscopic examinations are not necessary. In general, it is recommended to follow the specific guidelines for the diagnosis of BPH.

As for other procedures, informed consent should include information about the different treatment options, including transurethral resection, and the specific advantages, disadvantages, risks, and potential complications of each method. Patients should be informed that surgical risks, such as significant bleeding or TUR syndrome, are rare or nonexistent. The chance of the patient retaining normal sexual function is approximately 80% [22, 23]. The patient should be aware that the failure rate for this procedure is about 10–15% within 1 year (for an unselected group of patients) and that postprocedure catheterization (permanent or intermittent [24]) will be necessary for some time. The patient should know that at present the longest follow-up is only 10–12 years and publications on long-term results are available for follow-up of 4, 5, and 7 years only [25–27].

Published reports of the complications associated with interstitial laser therapy and their incidence include complicated UTI with fever or epididymitis or prostatitis (0.5%), transient stress incontinence (0.1%), urgency, and strictures of the urethra or bladder neck (2–5%), including recurrences of pre-existing, simultaneously treated strictures [13–16, 22, 23, 28, 29]. More frequent are uncomplicated UTIs in about 10–35% of patients and transient irritative symptoms in 9–15%; tissue sloughing also has been noted. Permanent incontinence has never been reported but should not be excluded from the list of potential risks.

Some risks can only be theorized, such as coagulation of the rectum with consequent fistulas, damage to the neurovascular bundle, and fiber breakage during irradiation that produces fiber fragments that must be removed by electroresection. With correct application techniques and equipment, these risks can be avoided. The incidence of these risks, however, has not been reported.

Preoperative preparation

Interstitial laser therapy can be performed with a local [6, 7], regional, or systemic anesthetic. If local anesthesia is chosen, such as by transperineal injection of lidocaine to achieve a blockade of the prostate and pudendal nerves, overfilling of the bladder, which could cause discomfort, should be avoided. Although no permanent irrigation is necessary during this procedure, a suprapubic catheter can be useful.

After adequate anesthesia is induced, the patient is placed in the dorsal lithotomy position. Routine disinfection and a noninflammable drape, as generally required for any laser surgery, should be used. If not previously done, a routine urethrocystoscopy is performed. A video camera and monitor are useful, but are not required. All general laser safety measures (e.g. warning signs and signals, and wavelength-specific eye protection) must be observed before, during, and after interstitial laser therapy.

Interstitial laser applicators can be placed using several different approaches [16, 30]. In practice, endoscopically-controlled transurethral placement has proved most useful. Neither percutaneous placement from the perineum nor transrectal placement guided by TRUS was used in the most recent series.

Instrumentation

Several laser wavelengths have been studied for use in interstitial laser therapy [10–12, 28, 31–35]; published reports have demonstrated that 800–1100-nm wavelengths offer relatively deep penetration depths in water and efficient volumetric heating, which permit the delivery of necrotic temperatures deep into tissues. These wavelengths can be delivered with flexible optical fibers; consequently, Nd:YAG lasers (1064 nm) were first used for interstitial laser therapy [36–40]. Experiments have shown that diode lasers emitting at approximately 805, 830, 940, and 980 nm, and even the Ho:YAG laser (2100 nm), are also suitable for generating large interstitial coagulation volumes [10–12, 28, 31–35].

Bare fibers, as used by Littrup *et al.* [41, 42] and McNicholas *et al.* [43] in animal experiments to evaluate interstitial laser therapy for prostate cancer and later by McNicholas *et al.* [30, 44–48] for BPH treatment, emit all laser energy from a very small area (0.3 mm^2 with a 600-μm fiber). Even with low-laser power, high-power densities are achieved (330 W/cm^2 with 1 W), leading to immediate carbonization and vaporization. Experiments have demonstrated that interstitial irradiation with a bare fiber at up to a 20-W power setting produces only a small spherical lesion of 5–10 mm diameter, consisting of a central cavity filled with debris, and adjacent char and a small coagulated rim [30, 38–40, 49, 50–55]. For LV-ILC this may be sufficient. To achieve HV-ILC, a very high number of applications is required.

To avoid charring and to achieve large-volume coagulation, the power density of an interstitial applicator must be much lower (5–10 W/cm^2) [40, 56]. Since Bown first discussed interstitial laser therapy for cancer treatment in 1983 [57], several types of applicators with larger irradiating surfaces have been used in laboratory or clinical experiments [35, 53, 58–65], but these have all produced similarly unimpressive results.

Interstitial laser therapy for BPH was a completely new concept, first described by Hofstetter and Muschter and coworkers [36, 37, 39, 49]. New types of applicators were specially designed. Two technical principles have been elucidated to extend the emitting surface [56, 66]. One solution is a diffusor tip that emits the radiation circumferentially and randomly in all directions in a more or less even pattern along the entire length of the applicator [66]. The other solution is a system emitting the laser radiation circumferentially in a forward direction (with a ring- or cone-shaped beam profile at an angle of approximately 45º in water). This is achieved by eliminating the transversal modes of the laser beam [56]. In tissue, through light reflection and predominantly scattering, the latter type of applicator acts almost like a diffusor tip, too. Both types of applicators create rather homogeneous coagulation zones around the emitting tip. These increase in size by conduction of heat to the periphery. Their final shape is ovoid, ellipsoid, or spherical [3, 31, 32, 40, 49]. Lesion length depends on the emitting length of the applicator; the radius of the lesion can be up to 1 cm (i.e. up to a diameter of 2 cm), depending on laser wavelength, laser power, and radiation time (*in vivo* maximal single lesion volume approximately 4–10 cm^3) [3, 40, 49, 67–77].

Interstitial applicators consist of an emitter (e.g. transparent quartz glass cylinder or Teflon coating) affixed to the distal end of a flexible 600-μm quartz glass fiber, with a specific cut of the tip in some types. Different dimensions have been tested; for routine use in the prostate, an emitter length of 2 cm and a diameter of approximately 2 mm were found to be the best compromise based on the technical requirements (large radiating surface) and surgical requirements (small size for simple handling). For ease in placement, the tip of the applicator is exaggerated [49]. The actual design of the interstitial applicators may vary among manufacturers [35, 56, 66, 78, 79].

The goal of interstitial laser therapy is to achieve a relevant coagulation volume in the shortest time. Although this can be achieved with multiple (successive or simultaneous) applicator placements, each single treatment volume should be large. Therefore, radiation parameters must be chosen to fulfill this requirement. Optimal parameters vary for different laser wavelength and applicator combinations [3, 28, 31–33].

Using constant laser power in the range 5–7 W, the maximum coagulation volume can be expected within approximately 10 min of irradiation time, without the risk of carbonization [37, 39, 40, 49]. Some laser/applicator combinations may be operated with a constant power of up to 10 W for 10 min.

More rapid heating by using higher laser power will reduce irradiation time but increase the risk of carbonization, or even make carbonization a certainty if the power density is above the carbonization threshold. For short irradiation times, however, high powers are tolerable. Therefore, various power formatting programs were designed and tested to achieve the maximum coagulation volume within the minimum total irradiation time [3, 31–33]. In this type of laser energy application, irradiation starts with a relatively high power that is reduced in repeated steps or continuously to maintain the temperature in the center of the lesion at the highest level just below the carbonization threshold. This allows further energy influx to increase the size of the lesion, and this power is maintained until a temperature balance is reached in the periphery [3].

A feedback system further optimizes energy application; in such a system, the actual emitted laser power depends on the temperature generated and measured at the applicator ("Indigo 830e"; Johnson & Johnson, New Brunswick, NJ, USA). Different optical feedback devices are also available for detecting carbonization at the applicator tip, thereby preventing thermal damage to fibers by automatically terminating laser irradiation.

The Ho:YAG laser can also be used in combination with an applicator specifically designed for interstitial laser therapy ("Auriga"; Wavelight, Starnberg, Germany). Experiments have demonstrated that lesion volumes equivalent to those achieved with the Nd:YAG or diode lasers can be generated by using high-pulse energies and relatively long pulse durations. Sufficiently large lesions were achieved in relatively short application times (usually 1 min, and in later experiments only 10 s) [10, 12]. Depending on the pulse frequency, the average laser power can be calculated. Interstitial lesions generated with the Ho:YAG laser consist of a central cavity and an adjacent zone of coagulation.

To achieve large lesions inside the prostate lobes, the laser applicator needs to be placed deep inside [80, 81]. The ideal angle would be perpendicular; however, in reality in transurethral placement, the applicator is rather tangential. Because the laser fiber is flexible with a rigid or fragile tip, if not properly guided, the fiber may slide along the surface, bend, and even break. Transurethral interstitial laser therapy requires a rigid scope with a working channel large enough to accommodate the fiber, usually between 5F and 7F. The viewing angle of the scope can range from 0º to 30º. An ideal instrument has a small separate working channel that ends at the level of the telescope for optimal stabilization of the fiber during puncture, such as the atraumatic urethrocystoscope described by Miller *et al*. [82] or the Gilling laser resectoscope. If a standard cystoscope with the usual "half-pipe" sheath tip is used, rotation may improve fiber placement.

Continuous irrigation is not required throughout the procedure. While placing the applicator, irrigation will optimize visualization of the prostate and laser fiber. Any sterile irrigation fluid can be used, such as saline solution or water. Auxiliary instruments for placing the fibers are not necessary. Any type of urinary catheter can be used for bladder drainage.

For percutaneous (perineal) interstitial laser therapy, a TRUS scanner is helpful [83], preferably one with an aiming device (e.g. template) as is used for the perineal placement of seeds for local radiation therapy of prostate cancer. For penetrating the skin and guiding the fiber into position within the prostate, a special cannula large enough to accommodate the applicator is used. With an outer diameter of approximately 2.1 mm and a sharpened tip, this cannula can be inserted without dilation [13, 14, 16, 40].

Operative steps (Figures 130.1 and 130.2)

The steps of the transurethral and perineal approaches are listed in Tables 130.1 and 130.2, respectively.

Technique

The goal of HV-ILC is to necrotize a large volume in each lateral lobe and the median lobe (if needed) to produce therapeutic results while preserving healthy tissue. The total number of fiber placements is dictated by the total prostate volume and configuration, but is ultimately dependent on the discretion of the surgeon. Any number of placements can be used. Generally, it is better to treat one extra site than one too few, because some overlap of the lesions needs to be taken into account. A general guideline is one to three applicator placements for each estimated 5–10 cm^3 of BPH tissue [15, 84–86]. Individual placements (in the tissue, not points of puncture) of the laser fiber should be spaced by about 0.5–1 cm and at different angles to minimize substantial overlap of treatment volumes (which is not harmful but wastes time), but be close enough so there are no gaps of untreated tissue. The points where the fibers are inserted can be close to each other.

While the final result of a successful HV-ILC regarding prostate volume reduction and decrease of BOO can be compared with TURP, LV-ILC is comparable to TUNA or transurethral microwave thermotherapy (TUMT) [1]. The treatment effect of LV-ILC is predominantly symptomatic improvement and is probably not related to volume reduction, but to potential destruction of afferent nerves, although this is not based on experimental data [87, 88]. The goal of LV-ILC is to generate symptomatic improvement in mildly obstructed patients with no or few unwanted side effects [89], such as the requirement of other than local anesthesia and the need for prolonged catheterization. The application technique is identical to that for HV-ILC, but with fewer numbers of fiber placements and/or different laser parameters (e.g. lower laser power, shorter irradiation time).

Fiber placement is basically limited by the proximity of the treatment volume to be produced to the prostatic urethra, prostatic capsule, and points along the prostatic urethra distal to the bladder neck and proximal to the external sphincter. With the ultrasound-guided perineal approach, this can easily be achieved by measuring and keeping the distance between the applicator and the urethra or the capsule on all sides at approximately 1 cm (the expected radius of coagulation). Likewise, staying within the limits with the transurethral approach is not difficult.

In general, the sites for fiber placement should be chosen where the mass or bulk of hyperplastic tissue is found. In the sagittal plane, fiber penetration should be in the direction of the urethra. With the patient in the lithotomy position, the direction of the prostatic urethra in most cases is approximately parallel to the operating table at the apex, turning ventrally near the bladder. Therefore, in the apical zone it is best to puncture the lateral lobes at the 3 and 9 o'clock positions, and penetrate parallel to the operating table. When closer to the bladder neck, it is suitable to penetrate more ventrally at the 10 and 2 o'clock positions. In larger prostates, multiple punctures at different fan-shaped angles are required.

It may be important to preserve the urethra to minimize symptoms following the procedure [90]. If the urethra is accidentally necrotized, however, ordinary tissue sloughing may occur and is not harmful (the treatment effect is then much like that of deep transurethral free-beam coagulation) [13–16]. Avoiding damage to the urethra requires both a minimum depth and angle of fiber penetration. The applicator should be inserted to a depth of at least 0.5 cm beyond the irradiating part. In most types of applicators, this corresponds to their proximal end, and in others to a fiber depth marker. The

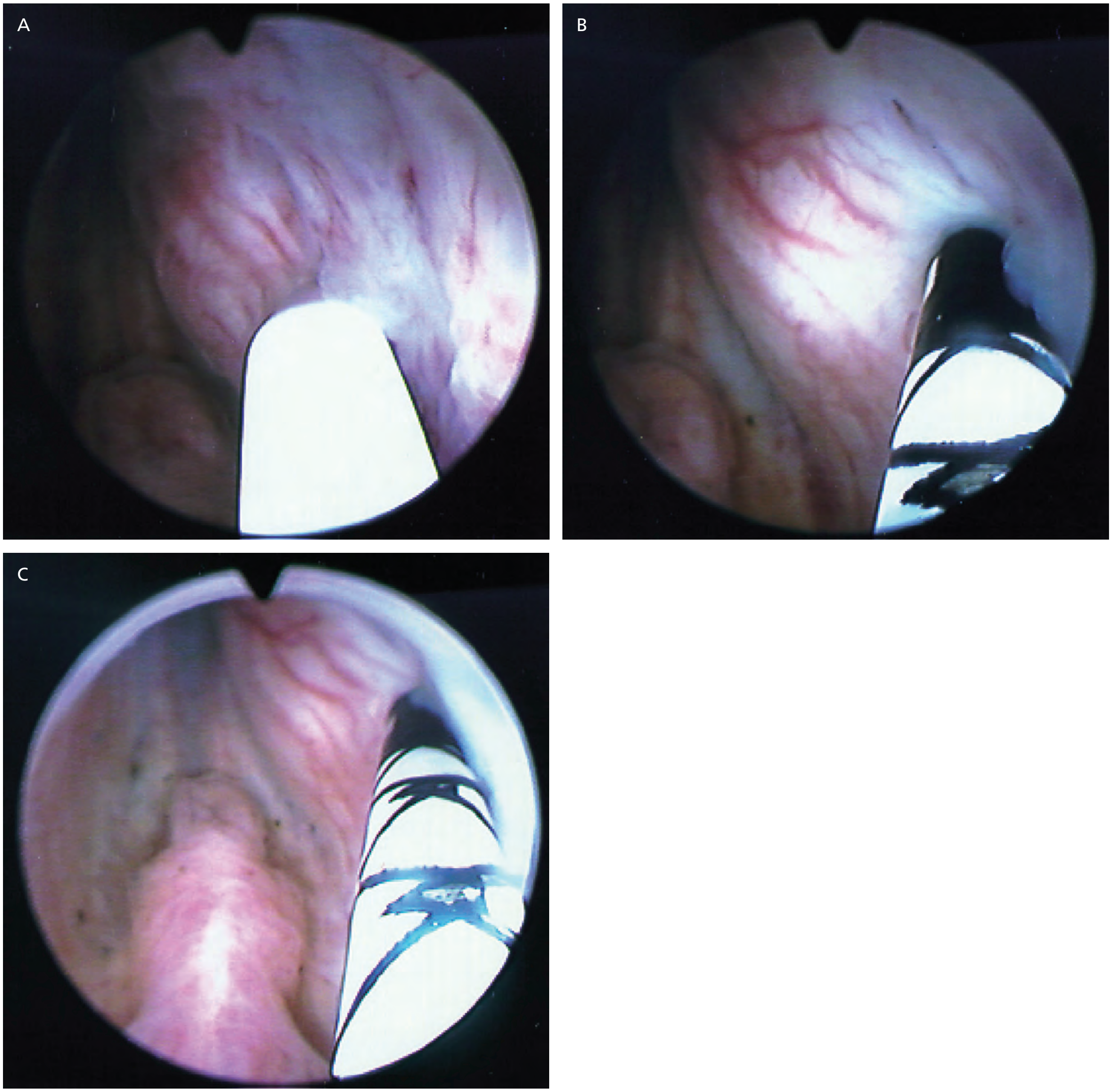

Figure 130.1 (A) Interstitial applicator just before insertion into the apical portion of the left lateral lobe. (B) Interstitial applicator completely inserted in the apical portion of the left lateral lobe, dorsal part. (C) Interstitial applicator completely inserted in the apical portion of the left lateral lobe, ventral part.

fiber penetration angle in relation to the longitudinal axis of the urethra should be the maximum achievable; in the apical zone this is approximately 45°. Closer to the bladder neck it is often less (20° in large prostates) because of the convex shape of the lobe. For effective treatment of this part of the lobe, it is also possible to insert the fiber at a point closer to the apex at a lower angle, and then carefully to penetrate deeper toward the bladder neck.

Coagulating the prostate capsule is unnecessary and should be avoided. In practice, fiber penetration to the lateral or ventral parts of the capsule is almost impossible because of the limited penetration angle and depth achievable, but it is probably not harmful or of clinical significance if it does occur. In addition, the highly vascular nature of the prostate capsule acts as a heat sink and contributes to preventing potential coagulation of the capsule itself and adjacent structures. However, for

Table 130.1 Operative steps in the transurethral approach.

1. Administer local anesthetic or initiate spinal or general anesthesia
2. Prepare the operative field and instruments
3. Instill lubricant gel into the urethra, connect the cystoscope to a light source and an irrigation container, and attach a video camera to the scope if appropriate. Insert and advance the cystoscope under direct vision into the bladder
4. Fill the bladder and place a suprapubic catheter if appropriate
5. Empty the bladder
6. Attach the laser fiber connector to the laser aperture
7. Activate the laser unit and set it in the standby mode
8. Insert the applicator into the cystoscope's working channel and advance it until it is visible
9. Retract the cystoscope and fiber together back into the prostatic urethra (wide angle view)
10. Choose a treatment point and advance the fiber to be just in contact but not penetrating the urethra. Hold the cystoscope's tip close to the treatment point and advance the cystoscope if necessary (almost to or to tissue contact)
11. Tilt the cystoscope laterally in the desired angle from the center axis of the urethra. In the sagittal plane, keep the cystoscope aligned in the direction of the urethra or, in voluminous lobes, angle it ventrally or moderately dorsally
12. Advance the fiber to puncture the urethra (Figure 130.1A). Observing the applicator's proximal end or fiber depth marker, insert the applicator completely or further to the desired depth (Figure 130.1B)
13. Activate the laser beam for the prescribed treatment duration
14. Set the laser in the standby mode. Retract the applicator into the cystoscope (Figure 130.2)
15. Repeat steps 10 through 14 at additional sites (Figure 130.1C) within the same and other prostate lobes until the desired volume of tissue has been treated. The order of punctures should follow a scheme
16. Inactivate the laser unit and remove all instruments
17. Place a transurethral catheter if appropriate

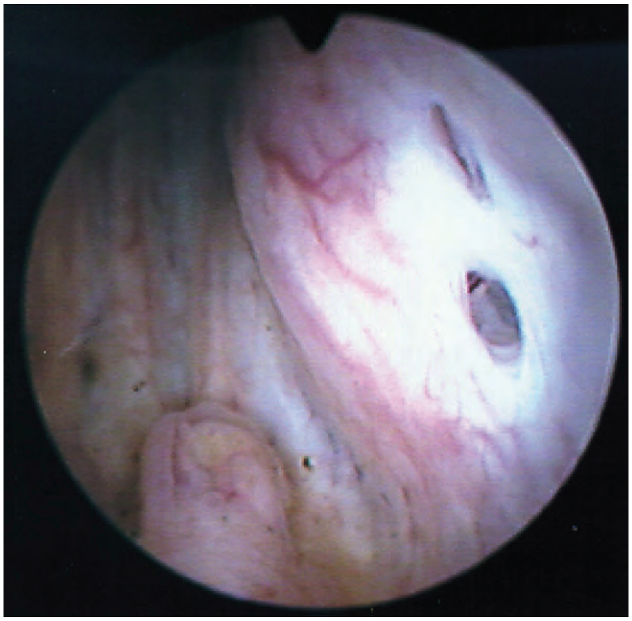

Figure 130.2 Puncture sites at the apical portion of the left lateral lobe, after removal of the laser fiber.

Table 130.2 Operative steps in the perineal approach.

1. Administer local anesthetic or initiate spinal or general anesthesia
2. Prepare the operative field and instruments
3. If necessary, perform a urethrocystoscopy. Place a suprapubic or transurethral catheter
4. Insert the transrectal ultrasound scanner and scan the prostate. Attach the aiming device (template)
5. Attach the laser fiber connector to the laser aperture
6. Activate the laser unit and set it in the standby mode
7. Choose a treatment point, insert the trocar cannula, and advance it to the desired depth and location under ultrasound guidance
8. Remove the trocar, insert the applicator into the cannula, and retract the cannula
9. Activate the laser beam for the prescribed treatment duration
10. Set the laser in the standby mode; remove the applicator
11. Repeat steps 7 through 10 at additional sites within the same and other prostate lobes until the desired volume of tissue has been treated
12. Inactivate the laser unit and remove all instruments

maximum safety, the applicator should not be advanced dorsally because there is little or no BPH tissue to treat and yet there is a potential risk of damaging structures adjacent to the prostate (e.g. neurovascular bundles and rectum) or inducing subtrigonal lesions with subsequent (relative) bladder neck strictures.

All puncture points must be within the length of the prostatic urethra between the external sphincter and the bladder neck. The puncture point closest to the bladder neck should be no closer than 1.5 cm from the bladder neck, so that it will not penetrate the bladder (except for treatment of a median lobe). Accidental penetration of the applicator through the prostate into the bladder can be detected by feeling resistance to fiber penetration. If the laser is activated and the bladder is full, there is no effect because of light diffusion and low laser power. If

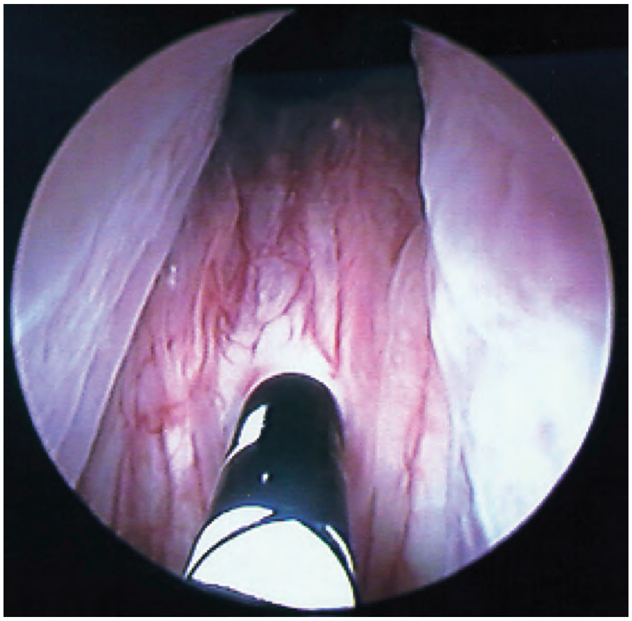

Figure 130.3 Puncture site for treating the center of the median lobe.

the bladder is empty and the fiber is in contact with the bladder wall, there is a chance of coagulating the bladder wall, which can be, but is not necessarily, a problem. If fiber penetration occurs, the fiber can simply be pulled back into the prostate and that site can be treated. The most apical puncture point should be in the prostatic urethra just in front of the proximal end of the external sphincter (see Figure 130.1) so that no apical tissue goes untreated. As discussed earlier, care must be taken to insert the applicators to the required depth.

When the median lobe is being treated, the fiber should be advanced in the direction of the bladder (Figure 130.3) to prevent subtrigonal penetration. A large median lobe should be treated with more than one puncture [5]. Depending on its size and shape, punctures can be made at different levels and angles. When puncturing the median lobe, pressure on the fiber usually pushes it towards the bladder before it penetrates; therefore tangential placement of the fiber may result. This can be avoided by a moderately dorsal direction of puncture. For the effective treatment of a median lobe, several fiber placements are necessary because of the large surface area that is cooled by the fluid in the bladder.

Adopting an order scheme for punctures can be helpful. There can be any starting point: bladder neck, apex, median lobe, or lateral lobe. If the first lesion is produced in the apex, the prostate becomes a little harder in that area because of coagulation. This firmness facilitates subsequent penetrations toward the bladder neck, which is a little more difficult to reach because of the limited space in the prostatic urethra.

While laser energy is being delivered into the prostate tissue through the applicator, it is better to stabilize the fiber and cystoscope by holding them manually rather than mechanically anchoring them (e.g. with a tripod). If a mechanical anchor is used, patient motion could pull the fiber out of the prostate.

Bleeding at a treatment site is usually slight or nil. Irrigation keeps the field clear. Deep punctures may bleed after the fiber is withdrawn because not all of the puncture channel is coagulated. Typically, all bleeding stops in a short time, and cautery is usually not required.

If a laser feedback system is used and detects carbonization during treatment [91], it will terminate irradiation at that treatment site. The applicator should be withdrawn and inspected. Usually it can be cleaned and used for subsequent treatment sites. Burned fibers should not be used again because fiber damage increases rapidly with subsequent use. Resumption of treatment with either the same or a new fiber should always proceed at a new puncture spot.

Approaches other than those already described are the transrectal [16, 30, 92] and the laparoscopic/pelvioscopic approaches [16]. The transrectal approach has no advantages over the perineal approach, but entails risks such as infection or bowel injury [30], so the latter approach may be suitable for the treatment of cancer but seems to be too aggressive for BPH.

On-line treatment control is possible with the use of magnetic resonance imaging (MRI) [75, 93, 94], as shown by several authors treating malignancies with interstitial laser therapy [20, 71, 72, 95–97]. In the treatment of cancer it is critical to leave malignant tissue untreated and therefore on-line treatment control is required; in BPH treatment, however, this would be too costly and is not necessary. TRUS is not suitable for on-line control because changes are detectable only when tissue is carbonized or vaporized. Multichannel rectal temperature monitoring can be performed for additional safety; direct temperature measurements in several patients in the tissue, prostate capsule, and rectum [13–16, 40] proved that (1) the desired temperatures with temporal and spatial distributions, as expected based on animal experiments [3, 4, 49, 98], were achieved in the treatment volume [99]; and (2) that no critical increases in temperatures were detectable in the capsule or surrounding organs, in particular the rectum [40]. Computerized calculations or simulations of the temporal and spatial temperature profiles [100, 101] provide no additional information and are not required for monitoring interstitial laser therapy of BPH.

Animal experiments have demonstrated that the combination of a systemically or locally administered photosensitive drug and laser therapy using a specific laser wavelength and a nonthermal energy range [photodynamic therapy (PDT)] could be useful for treating BPH

[102]. Early trials with interstitial PDT using different photosensitive agents were undertaken some years ago to treat prostate cancer [103, 104]. Although no major breakthrough was achieved, the concept seems promising but requires further investigation.

Postoperative care

Following interstitial laser therapy, a catheter (either a 10F or 12F suprapubic catheter or a 14F or 16F urethral catheter) is left in place to provide urinary drainage. Since bleeding seldom occurs, bladder irrigation is usually not required but can be useful in individual cases for a few hours to prevent clot retention.

Heuck *et al*. [69, 70] and Mueller-Lisse *et al*. [73, 75–77] report that postprocedure MRI demonstrates a marked increase in prostate volume, returning to the preprocedure value within about 5–7 days. In addition, because of the coagulation, the consistency of the prostate tissue becomes firmer, thus usually resulting in a temporary increase in the degree of obstruction. Consequently, voiding function and obstructive symptoms are usually temporarily worse, somewhat correlating with the coagulation volume. Therefore, the majority of patients require urinary drainage for a few days. Patients with moderate-to-good detrusor function are able to compensate for the acutely increased obstruction. In this group, the catheter can be removed early. Patients with chronic retention or with poor or decompensated detrusor function, however, will require the catheter for a longer time. In principle this is not specific to interstitial laser therapy but applies to all procedures without substantial immediate tissue removal. The need for and duration of catheterization is different in HV- and LV-ILC [79].

If a transurethral catheter is used, it should be taken out after 3–7 days. Patients who fail to void should be catheterized for another week. If a suprapubic catheter is used, it is usually clamped on the first day. Continuous voiding training can be done during the day with regular control of the PVR, while at night sufficient drainage can be achieved. If voiding function becomes satisfactory, the suprapubic catheter should be removed. This can be expected within 1 week for most patients.

During the weeks following HV-ILC, a continuous volume reduction of the prostate is observed with shrinking of the coagulated lesions [13–16, 40, 49]. Only small residues are detectable after 6 weeks and vanish completely within another 4–6 weeks [69, 70]. In this period symptoms and voiding function continue to improve in most patients. A few patients show a more stepwise, often dramatic, improvement that can occur at any time during follow-up, even after 3 months.

Subjective satisfaction is usually achieved within 2–6 weeks, and a substantial objective improvement in Qmax and prostate volume in HV-ILC can usually be measured after 4–8 weeks. The final outcome can be judged after approximately 3 months.

Results

Several studies have indicated the effectiveness of interstitial laser coagulation of BPH regarding all of the three characteristics of the disease: symptoms, obstruction, and enlargement [9, 13–16, 29, 105–111].

In the initial study, 239 patients were treated at Grosshadern Hospital of Munich University from July 1991 through October 1993 [13–16]. During this time, many technical and procedural improvements were made and the difficulties that arose during the learning curve were overcome. The results were encouraging and compared well with published reports of TURP; in fact, the results were superior to most other alternative treatment modalities of that time [14, 17, 110]. The multivariate analysis showed no factors predicting final success or failure, such as initial symptoms, flow rates, residual volumes or prostate volumes, and endoscopic or perineal access, except the number of cases previously performed by the surgeon (reflecting the learning curve). Interstitial laser therapy was safe, with a low potential for severe side effects. Retreatment for persistent voiding problems was necessary within 1 year in 9.6% of patients. For the early treatment group, follow-up was up to 30 months at the time of evaluation, with only a few more patients requiring retreatment. In Japanese studies, Arai *et al*. found a strong correlation between the number of punctures in relation to prostate volume and clinical outcomes [85, 106, 112–114].

Since then, many studies, including prospective randomized studies versus TURP, have been reported, and data are available on subjective improvements in symptoms and quality of life, and on objective improvements in urinary flow rates and PVR. In some studies, volume measurements gave outcomes on prostatic volume reduction, and pressure–flow studies on urodynamic improvement (Tables 130.3 and 130.4).

Several authors have used interstitial laser therapy for the treatment of BPH [9, 105–111]. Some have used the LITT light guide and transurethral application technique. Henkel *et al*. [108], Janetschek *et al*. [109], and Horninger *et al*. [110] employed LITT light guides as well, but inserted them exclusively from the perineum under TRUS guidance. The latter group used a three-dimensional imaging system [109, 110]. Handke *et al*., who also performed interstitial laser therapy transperineally, used another application system [78] specifically designed for interstitial treatment [111]. McNicholas *et al*. employed bare fibers, which they inserted under TRUS guidance, either transrectally into the side lobes or transurethrally for isolated median bar obstruction [17]. The vast majority of studies, however, were

Table 130.3 Clinical results of interstitial laser coagulation of benign prostatic hyperplasia.

Study	Procedure (number)	Follow-up (months)	IPSS preoperative	IPSS postoperative	Qmax preoperative (mL/s)	Qmax postoperative (mL/s)	Retherapy TURP (%)	Volume reduction (%)
AFU multicenter (1998) [115]	TURP 16	12	N/A	9.3	N/A.	18.7	N/A	N/A
	ILC 27		N/A	6.9	N/A	15.4	N/A	N/A
Arai *et al*. (1996/2000) [85, 112, 113]	ILC 76	6	18.9	7.7	6.7	10.0	7.1	14.8
		12	19.7	7.4	7.1	11.1	N/A	16.4
Bloch (1994) [107]	ILC 28	3	N/A	N/A	5.0	14.3	3.6	N/A
Chandrasekar *et al*. (2007) [26]	TURP 50	60	N/A	N/A	N/A	N/A	N/A	N/A
	ILC 100		20.5	8.0	8.4	14.6	N/A	N/A
Conn *et al*. (1996) [116]	ILC 12	3	22.6	6.0	7.1	14.1	N/A	N/A
Conn *et al*. (1999) [117]	ILC 165	12	22.4	8.3	8.6	14.2	6.0	N/A
Daehlin (1999) [118], Daehlin and Hedlund (1999) [119]	ILC 49	12	22	11	8.6	9.9	N/A	N/A
De la Rosette *et al*. (1997) [120, 121]	ILC 25	3	20.6	6.9	9.1	20.3	0	N/A
De la Rosette *et al*. (1996) [122]	TURP 56	6	22.4	6.5	8.3	20.3	N/A	N/A
	ILC 110		21.5	9.7	8.3	14.0	N/A	N/A
Fay *et al*. (1997) [123]	TURP 24	6	22.5	8.6	8.8	18.9	N/A	N/A
	ILC 20		23.0	10.8	7.5	11.6	N/A	N/A
Ferguson *et al*. (2000) [124]	ILC 25	4	22.0	10.9	9.7	15.6	N/A	N/A
Floratos *et al*. (2000) [125]	ILC 53	12	20	7	8.0	13.5	1.9	N/A
		24		7		10.7	13.2 (15.1)	
		36		10		12.0	9.2 (24.3)	
Greenberger and Steiner (1998) [126]	ILC 25	6	20.2	8.8	8.3	14.1	N/A	N/A
Handke *et al*. (1994) [111]	ILC 13	2	N/A	N/A	N/A	N/A	15.4	N/A
Henkel *et al*. (1995) [127]	ILC 35	3					8.6	
		12	21	8	5.3	10.0	13.6	35.8
Horninger *et al*. (1995) [128, 129]	ILC 12	12	29	6	8.3	16.9	0	8.3
Kim *et al*. (2006) [130]	TURP 110	12	24.0	8.8	11.9	22.9	N/A	N/A
	TUNA 110						N/A	N/A
	ILC 89		21.1	7.9	8.6	19.6	N/A	N/A
Knoll *et al*. (2003) [27]	ILC 72	84	18.8	8.8	N/A	N/A	15.8	N/A
Krautschick et al. (1999) [131]	ILC	24	N/A	N/A	N/A	N/A	11.9	18
Kursh *et al*. (2003) [132]	TURP 37	24	23.0	7.0	9.1	16.5	0	N/A
	ILC 35		24.0	9.0	9.2	13.9	16	15.4
Liedberg *et al*. (2003) [133]	TURP 11	12	17.0	6.0	8.0	14.0	N/A	N/A
	ILC 20		19.0	11.0	8.0	11.0	N/A	N/A
Lynch *et al*. (2000) [89]	ILC 39	6	23.5	6.1	8.4	18.4	N/A	N/A
Martensen *et al*. (1999/2003) [134]	TURP 14	24	21.6	5.0	9.3	25.7	7.0	N/A
	ILC 30		21.7	12.0	7.3	11.9	20.0	N/A
Martov *et al*. (1998) [135]	ILC 42	24	23.7	9.2	6.5	13.9	N/A	N/A
Martov and Kilchunov (1996) [136]	ILC 25	6	19.9	13.5	8.7	13.5	0	21.8
Matsuta I. (2003) [137]	ILC 45	24	18.0	5.7	7.6	11.6	N/A	N/A
McNicholas and Alsudani (1996) [48]	ILC 36	12	22	7	9.4	14.6	0	N/A
Meagher (1996) [138]	ILC 36	N/A	N/A	N/A	N/A	N/A	8.3	N/A

Continued

Table 130.3 *Continued*

Study	Procedure (number)	Follow-up (months)	IPSS preoperative	IPSS postoperative	Qmax preoperative (mL/s)	Qmax postoperative (mL/s)	Retherapy TURP (%)	Volume reduction (%)
Minardi *et al*. (2004) [139]	TURP 90	24						48.8
	TVP 13							5.2
	TUNA 24							
	WIT 13							
	ILC 71							
Muschter and Hofstetter (1995) [14–16, 28]	ILC 239	12	25.4	6.1	7.7	17.8	9.6	38.6
Muschter *et al*. (1995) [8, 29]	TURP 49	12	31.1	3.5	8.9	25.6	0	N/A
	ILC 48	12	31.0	2.3	9.4	19.7	8.3	N/A
Muschter *et al*. (1996) [99]	ILC 112	6	20.9	7.9	8.0	14.2	11.9	N/A
Muschter *et al*. 1996 [140, 141]	ILC 42	3	22.1	4.2	8.2	24.9	2.7	41.6
Muschter *et al*. (1999) [23]	ILC 394	12	24.2	6.3	7.9	17.2	N/A	N/A
		24		6.8		15.7	N/A	N/A
		36		7.9		15.2	N/A	N/A
Nishizawa *et al*. (2003) [21, 24]	ILC 28	3	23.1	8.0	AUR	11.2	N/A	N/A
Norby *et al*. (2002) [142]	TURP/TUIP 24	6	21.3	6.8	9.6	20.6	N/A	N/A
	TUMT 46		20.5	9.5	9.1	13.2	NA	N/A
	ILC 48		21.4	9.5	10.2	16.2	NA	41.0
Orovan and Whelan (1994) [105]	ILC 16	3	16.3	5.8	8.8	11.9	0	n.a.
Pypno and Husiatynski (2000) [143]	TURP 112	48	22.3	6.7	5.9	17.0	3.5	N/A
	VLAP 117		22.6	6.4	4.4	14.3	14.5	N/A
	ILC 30		20.7	4.6	3.8	11.4	6.6	N/A
Rodrigo Aliaga *et al*. (1998) [144]	TURP 21	6						
	TUIP 20							
	VLAP 21							
	ILC 18							
Roggan *et al*. (1994) [145]	ILC 27	2	14	5	8.0	13.0	4.0	26.5
Schettini *et al*. (1996) [146]	ILC 20	3	22.6	9.2	7.9	15.0	5.0	26.4
Terada *et al*. (2004) [25]	ILC	48	N/A	N/A	N/A	N/A	22.0	N/A
Tsui *et al*. (2003) [147]	ILC	N/A	N/A	N/A	N/A	N/A	N/A	26.8
Wada *et al*. 2000 [148]	TURP 30	12						
	VLAP 20							
	ILC 30							
Whelan (1997) [149]	ILC 112	6	18.2	8.2	10.4	17.0	N/A	26.1
Whitfield *et al*. (1996) [150, 151]	ILC 40	6	19.0	8.1	8.4	14.3	N/A	N/A
Williams (1998) [84]	ILC 25	12	23.2	7.2	8.4	16.8	N/A	N/A
Williams (2000) [152]	ILC 312		22.1		8.6		N/A	N/A
	252	12		10.1		14.1		
	176	18		9.8		14.6		
	75	24		6.6		15.6		
Zhenghua and Ciling (1996) [9]	ILC 78	3	22.5	8.5	9.8	16.5	0	30.0

AFU, Association Francaise d'Urologie; AUR, acute urinary retention; ILC, interstitial laser coagulation; IPSS, International Prostate Symptom Score; NA, not applicable; Qmax: maximum urinary flow rate; TUIP, transurethral incision of the prostate; TUMT, transurethral microwave thermotherapy; TUNA, transurethral needle ablation; TURP, transurethral resection of the prostate; TVP, transurethral electrovaporisation of the prostate; VLAP, visual laser ablation of the prostate; WIT, water-induced thermotherapy; N/A, not available.

Table 130.4 Results of pressure–flow studies with interstitial laser coagulation of benign prostatic hyperplasia.

Study	Procedure	Decrease of detrusor pressure at Qmax
Daehlin and Hedland (1999) [119]	ILC	17 cmH_2O
Ferguson *et al*. (2000) [124]	ILC	6.4 cmH_2O
Horninger *et al*. (1995/1997) [128, 129]	ILC	11 cmH_2O
Krautschick *et al*. (1999) [125]	ILC	58 cmH_2O
Minardi *et al*. (2004) [139]	ILC TURP TVP TUNA WIT	38.3% 48.8% 53.3% 34.8% 27.5%
Zellner *et al*. (1994) [153]	ILC	20.3 cmH_2O

ILC, interstitial laser coagulation; TUNA, transurethral needle ablation; TURP, transurethral resection of the prostate; TVP, transurethral electrovaporization of the prostate; WIT, water-induced thermotherapy.

performed transurethrally using the 830-nm diode laser system [84, 89, 99, 116, 117, 120, 121, 124–126, 130, 132, 139, 140, 141, 143, 144, 150, 154].

Some studies were done on specific groups of BPH patients. Horninger *et al*. treated a selected group of 12 patients with large prostate glands (average volume 57 mL) [110]. Henkel *et al*. treated 38 high-risk patients and recorded an AUA score improvement of 26 to 9 after 6 months [108]. TRUS volumetry of the prostate showed a decrease in volume of 5–48%. The Qmax improved to over 15 mL/s in 50% of patients, and detrusor pressure normalized in 45% of patients. Bloch treated 28 outpatients, 14 of whom had chronic urinary retention [107]. Qmax improved from 5.0 to 14.3 mL/s (9.0–41.0 mL/s) and PVR from 152 to 54 mL on average [73].

Arai *et al*. treated 50 patients [106]. Although they performed only two to six fiber placements, they found that 80% of their patients were completely satisfied and had an AUA score improvement from 20.1 to 10.0; Qmax increased from 7.0 to 9.5 mL/s, and PVR decreased from 90 to 45 mL within 3 months. The prostate volume decreased from 33.5 to 27.5 mL. The retrospective analysis of these results leads to the interpretation that this was the first report on LV-ILC.

Complications

Specific complications of interstitial laser therapy are extremely rare. McNicholas *et al*. observed the only serious complication reported in the literature, which was a small bowel injury that occurred in one patient treated with a bare fiber that was inserted transrectally [47]. In theory, it is possible when using interstitial applicators and transurethral or perineal access that coagulation of the prostate capsule and adjacent organs may occur, but even if it does, this would probably not be of clinical significance in most cases. Coagulation of the neurovascular bundle and the rectum (the latter resulting in a fistula) could occur, but by avoiding extremely deep fiber placement, especially in a dorsal direction, this is highly unlikely. No reports on such events can be found in the literature.

In interstitial laser therapy the light applicators are placed into the tissue. Theoretically, they could break for one of two reasons: mechanical stress or overheating. A high degree of straining of the fiber can result in mechanical damage. In some types of applicators, damage can occur internally only and no parts can break off. If the tip were to break off, the stress point would always be outside the tissue at its surface. Therefore, the broken-off part of the applicator could easily be removed with forceps. Overheating because of the formation of char at the applicator tip could lead to a fiber breaking off inside the tissue. Most laser systems for interstitial therapy therefore have feedback systems that detect charring and switch the system off before the applicator can break. In the unlikely event of broken fiber fragments remaining in the tissue, they can be removed by electroresection, but in our experience and that of other groups this has never happened [37, 39, 40, 108, 110].

Other possible complications and side effects are not specific to interstitial laser therapy. Bleeding, if it occurs, is most often caused by mechanical trauma (e.g. of varicose veins on the urethral surface resulting from motion of the cystoscope). Minor bleeding from puncture sites is also possible. Bleeding usually stops within a short time without further treatment. To prevent clot retention, postoperative irrigation can be done for several hours. Significant bleeding from interstitial laser therapy is extremely rare; in all of the few reported cases it has been caused by the suprapubic catheter [12]. Unintentional infusion of irrigant or a significant TUR syndrome has not occurred in interstitial laser therapy [11, 15]. A mechanical perforation of the bladder or the prostate capsule is extremely unlikely to occur and has never been reported.

Frequently in the early postoperative period a transient increase in obstruction and a concomitant increase in obstructive symptoms occurs. Transient irritative symptoms such as urgency can also occur. These are usually caused by edema but can also be associated with either secondary uncomplicated UTI or urethral necrosis. In the latter case, parts of the urethra are most likely coagulated as a result of placement of the applicator close to the urethra. This is often accompanied by tissue sloughing [14, 15]. No specific treatment of these conditions is required. Permanent incontinence has never been reported. The rate of UTI, which can occur because of postprocedure catheterization, can be kept low by simple antibiotic prophylaxis [14]. Significant UTI with fever, epididymitis, or prostatitis can occur after interstitial laser therapy with the same frequency as after any other transurethral procedure.

Urethral strictures or bladder neck strictures, which occurred in approximately 5% of patients in the first series, resulted from instruments and application technique that required further refinement and development [14, 15]. In the more recent series, the urethral strictures observed were recurrences of previously treated strictures [28, 29].

Patients' sexual function regarding libido and erection was not affected by interstitial laser therapy in the initial studies [14, 15]. A loss of prograde ejaculation is possible. In the first series of patients, 93.3% of the sexually active patients responding to a questionnaire indicated that they had retained normal ejaculation patterns [14–16]. Most authors either did not report on retrograde ejaculation or inability to ejaculate or did not encounter this complication [105, 107, 108, 110, 111]. Arai *et al*. found retrograde ejaculation in two of 50 patients [106]. In an international multicenter study, this complication was observed in 6% of patients [28]. If an additional bladder neck incision is performed, however, the rate of loss of prograde ejaculation can be higher [8, 29].

The serum concentration of PSA increases dramatically after interstitial laser therapy; within a short time, however, it returns to the pretreatment level [15]. A late recurrence of increased PSA level during follow-up must be looked at carefully. In conjunction with digital rectal examination, PSA can still be used for cancer screening.

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CHAPTER 131

Electrosurgery of the Prostate: Improvements in Electrosurgical Unit, Transurethral Vaporization of the Prostate, and Bipolar Resection

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Historical development

The safe application of electrical energy to living organisms has underpinned many important surgical advances in the past two centuries. The first transurethral application of electricity to the human prostate was credited to the Italian, Enrico Bottini (1874); later, Wishard applied electrosurgical energy to the prostate under visual control, and Beer was the first to apply electrocautery under visual endoscopic control in a fluid environment. Hugh Hampton Young used a cautery punch device in 1911 to remove prostate tissue with a continuous flow instrument. William T. Bovie's pioneering design of an electrosurgical unit (ESU) combined a powerful cutting current and a damped coagulating current with separate footswitch control, which endures as the basis for modern electrosurgical generators.

In 1948, Iglesias de la Torre designed a spring mechanism in the resectoscope working element, allowing full control over the forward electrode excursion with a passive return excursion, while Baumrucker devised one that had exactly the opposite action. Endovisualization improved incrementally with Hopkins' rod–lens system, high-intensity external light sources, and video-camera miniaturization and high definition. Better antibiotics and anesthetic techniques, irrigant warming, and wider availability of blood transfusion, all helped to establish the place of the modern day transurethral resection of the prostate (TURP).

Impact of the electrosurgical unit and electrode configurations

Electrosurgical frequencies of greater than 100 000 Hz (radiofrequency range) avoid undesirable neuromuscular contractions and heat tissue by Ohmic resistance. Besides waveform, active electrode size and configuration affect current density and hence tissue effects. Rapidly reversing cyclical changes in molecular polarity lead to rapid intracellular water heating near the active electrode. This results in instantaneous steam production and cellular rupture, leaving a powdery residue and a tissue defect (the mechanism of monopolar electrosurgical tissue cutting). Irrigants must be nonconductive to localize current effects to the application site, while dissipating surface heat through conductive thermal transfer, and tissue circulation provides a deeper heat sink. The final tissue effects are governed by the maximum temperature achieved, the total time this temperature is sustained, and the rate of increase to the maximum temperature. Slow temperature rise times and/or low total thermal dose denature cellular proteins to desiccate cells, leading to coagulation necrosis. A rapid temperature increase greater than 100°C causes intracellular water to boil and, depending on power density, cells are desiccated, carbonized, or vaporized. Cutting and coagulation can also be produced by modifying electrical energy delivery, either by the source ESU or active electrode shape, or by modifying the surgical contact. For tissue cutting or vaporization, a voltage

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high enough to produce an electrical arc from the active electrode to the tissue surface (i.e. peak >200 V) is required, remembering that arc formation is hampered by active electrode direct tissue contact during footpedal activation. This aspect of surgical technique, where the cut pedal is activated just before contact with the tissue to get the most efficient arcing, which is sufficient to form a plasma vapor to conduct subsequent current more efficiently, is of paramount importance when an active electrode of large surface area is used for a cutting effect, as in transurethral vaporization of the prostate (TUVP).

In contrast, the coagulation waveform differs from that used for cutting by being *damped* and *pulsed* to increase peak voltage for deeper tissue penetration and slower heat rise time, resulting in hemostasis through desiccation and coagulation below the tissue surface. Nevertheless, tissue cutting can still be achieved with this damped coagulation waveform if the power is increased, but this is self-limiting as there is rapid electrode and tissue surface carbonization, which insulates deeper tissue from further efficient vaporization. A better way to achieve simultaneous tissue vaporization and coagulation during transurethral surgery is to exploit the principles of cutting current density by *reducing contact size and surface*. Hence, for the same current in the cutting mode, a point electrode (or a thin-wire loop in endourology) provides excellent cutting, while a flat electrode with a larger surface area (or a barrel roller electrode) provides good surface coagulation. The unique combination of ridges or surface spikes (high-current density areas) with larger contact points (low-current density areas) in a single electrode allowed simultaneous tissue cutting and surface coagulation (transurethral vaporization of the prostate (TUEVP) using only a pure cutting current waveform for the first time. Balance is critical in surface and size design to avoid excessive desiccation leading to limited tissue removal and irritative symptoms. Increasing power simply results in greater charring, while running the electrode over the tissue to "clean off" the accumulated debris impairs tissue removal.

Variables affecting tissue removal during electrovaporization

Beyond electrode configuration, the electrode drag speed [1–3], reuse (diminishes the vaporization effect by 50%), and power curves of different generators are all critical [4, 5] Two clinical studies of photothermal interstitial thermometry during loop resection and electrovaporization with a variety of different electrodes and ESUs confirmed the findings that there was no excessive heating of the neurovascular bundles, while reaffirming the surface heat sink effect of continuous flow irrigation (Figure 131.1) [6, 7]. Importantly, both sets of authors cautioned against prolonged applications of coagulating current, either at the level of the prostatic capsule or at the apex, for the higher peak voltage of the coagulating waveform facilitates deeper penetration and risks indirect and unseen neurovascular bundle damage at the apex or near posterior capsular perforations, particularly in small glands. In summary, these studies highlighted the fact that urologists must pay greater attention to many variables, such as electrode size and configuration, slower electrode excursion speed, and tissue contact pressure.

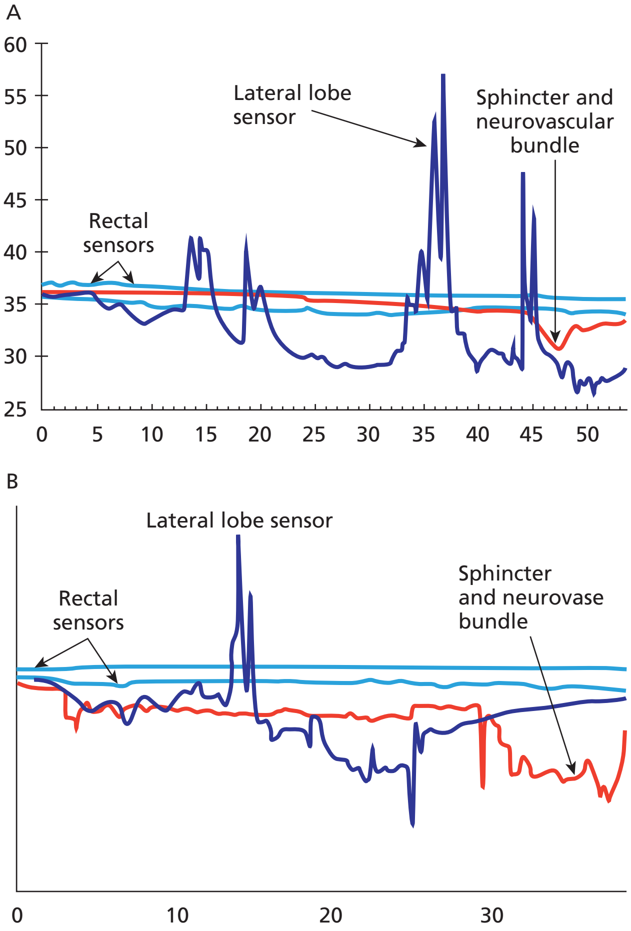

Figure 131.1 (A) Interstitial optical thermometry demonstrating temperature changes during transurethral resection of the prostate (TURP), and (B) during transurethral vaporization of the prostate (TUVP), confirming no unseen deep heating of vital structures, and protective cooling effect of continuous flow irrigation at the apex as the cavity is created.

Improvements in electrosurgical unit technology

Contemporary ESUs have adopted integrated computer-controlled technology to monitor "real time" current and voltage and autoregulate feedback according to the tissue impedance. Later generation ESUs either maintained constant *voltage* by automatically varying current and power (e.g. ERBE ICC 350; ERBE USE, Marietta, GA, USA), or constant *power* by automatically varying current and voltage output (e.g. Valleylab Force Fx™; Valleylab, Boulder, CO, USA). This helped to retain consistency of tissue interface effects within certain tolerances, allowing prostate electrovaporization at pure-cut settings below 200 W.

Some ESUs have incorporated special voltage-driven effects to improve tissue coagulation with loop and point electrodes. The ICC 350 unit from ERBE is one such device, and it has several incremental "high-cut" modes, which provide peak voltages between 400 and 700 V for deeper tissue penetration and coagulation. The combination of such units with loops that are thicker may produce marginally better hemostasis, although, so far in the published literature, this has not been significantly better than that obtained by an electrovaporization electrode coupled to an efficient generator and correct operative technique.

In an extension of the use of blended currents to reduce the bleeding associated with standard monopolar resection, in the mid 1990s, "coagulating cutting" was developed by Karl Storz (Tuttlingen, Germany), whereby phases with predominant cutting were alternated with shorter defined phases of coagulation. In clinical trials, however, the technique was disadvantaged by longer operative times related to a slower cutting speed due to a tissue drag effect during the phases of coagulation. To counteract this drawback, high-voltage pulses were introduced for the phases of coagulation, and coagulating intermittent cutting (CIC) came into existence. The output signal of the generator was a pulse-modulated sinusoidal wave of variable high amplitude voltage "tuned" for optimized cutting, but this time, due to sparking from the high-voltage pulses in a minority of cases, gas bubble formation increased and impeded the operator's vision. The last modification of the CIC generator deployed a controlled but variable (rather than fixed) pause between the cutting and coagulating pulses, each of which were of fairly constant voltage. In so doing, if power output decreased, the lag between the two pulses increased so that less power was delivered to the patient. However, once again, the energy load applied to the patient was higher, as with TUVP, and as before, no disadvantage was accrued [8].

A different strategy was used by Aesculap (Center Valley, PA, USA) with the Focus 640 ESU, to try to reduce excessive tissue charring during monopolar electrosurgical cutting with thin-wire electrodes. Its laboratory tests had apparently shown that the intensity of the monopolar electrode sparking, though well-defined at the moment of contact and at release of tissue contact, was variable through the duration of the cut itself. Consequently, it developed Microcut modes, which reduced the internal dosage voltage in such a way that a predetermined spark limit would not be exceeded if extensive sparking was detected. Thus, the Microcut modes limited spark intensity and minimized effective power at the electrode for an excellent cutting effect, while avoiding collateral tissue damage.

Bipolar prostate electrosurgery

Technology

This technology updated and revitalized a technique that was tried in the early decades of the last century. What then was the attraction of such technology over standard monopolar loop resection? The IEC60601-2-2 definition of bipolar is that it is a method of applying high-frequency output current to a patient via multiple-pole active electrodes. It permitted electrosurgical tissue cutting in conductive saline, offering urologists the possibility of using more endoscopic resection time and tackling larger glands without risking morbidity from water absorption and TUR syndrome.

As with monopolar cutting, the generator must initially produce a momentary high-energy spike to initiate a plasma vapor layer ionized in the form of a nonequilibrium plasma, where plasma ions and electrons are responsible for current flow. Unlike monopolar surgery, the current does not arc to the tissue and a return electrode with a large surface is not required. Instead, both active and return electrodes are in close proximity, separated by an insulator. The electron emission from the smaller active electrode vaporizes the adjacent liquid to form a thin gas layer (plasma pocket) that grows to form a larger bubble containing energetic species that can dissociate both water and organic molecules (Figure 131.2). It is likely that the thermal effect probably occurs at much lower temperatures (<70° C) compared to that with monopolar surgery (300–400° C).

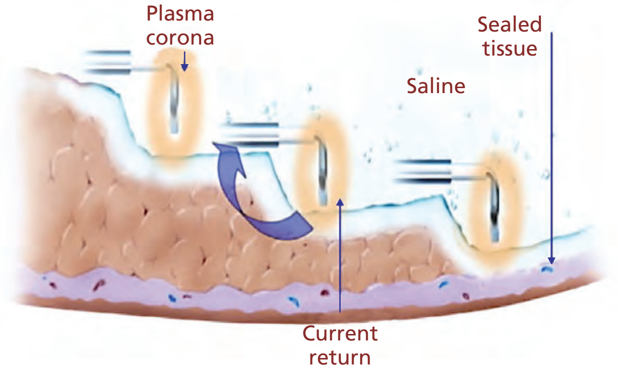

Figure 131.2 Formation of plasma pocket around active electrode and return pathway of current.

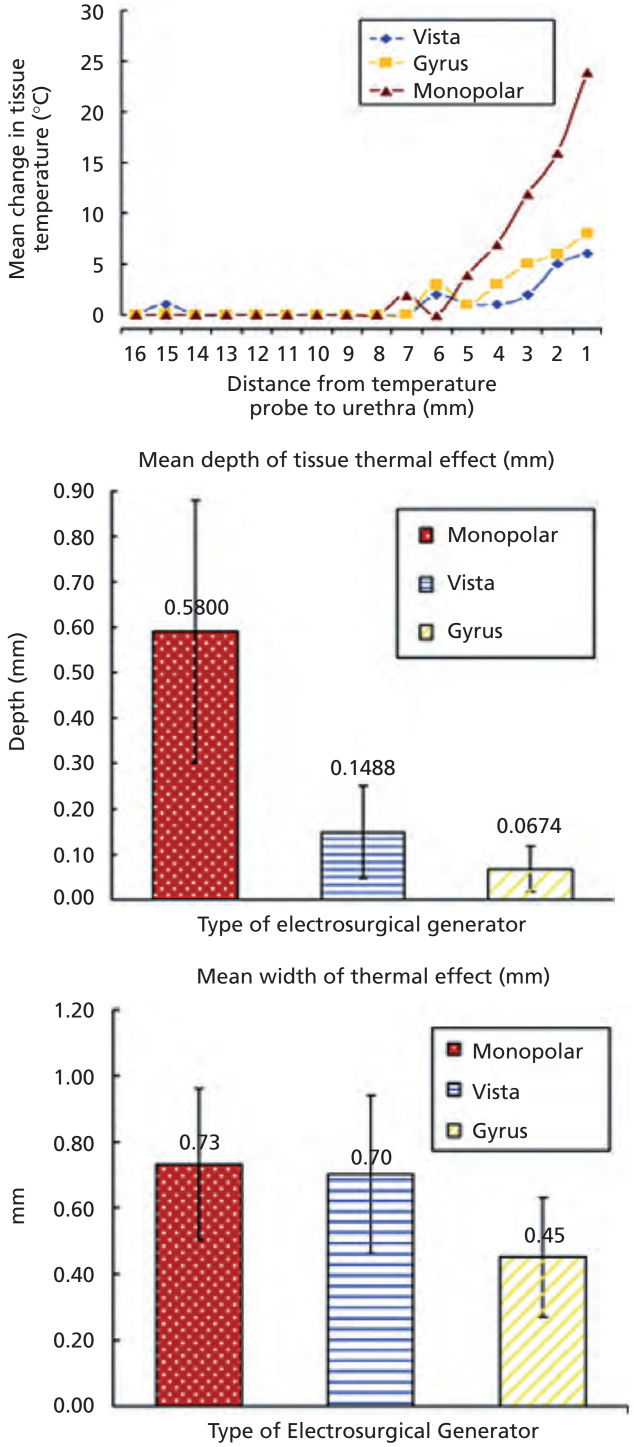

Figure 131.3 Thermal penetration in tissue comparing monopolar and bipolar or PK systems (reproduced from Ko *et al.* [9], with permission).

All bipolar technologies use radiofrequency (RF) energy output from specialized ESUs [320–450 kHz for Gyrus PlasmaKinetic (Gyrus Medical, Maple Grove, MN, USA; now acquired by Olympus, Tokyo, Japan), 100 kHz square wave for the now discontinued Vista Coblation system (ACMI Corporation, Southborough, MA, USA) and 350 kHz for the Olympus SurgMaster generator . A recent study by Ko *et al.* compared the heating effect and histopathologic effect of bipolar (Gyrus PlasmaKinetic and Vista) versus monopolar TURP in a canine model (Figure 131.3); they showed significantly less heating (including near the neurovascular bundle) and less evidence of thermal damage with bipolar compared to monopolar diathermy [9]. The energy passes down the active electrode, through the plasma pocket and thence through the conductive solution to the tissue bed before returning to the thicker return, and then finally returning to ground through the active cord. Furthermore, the combination of low operating frequency and low voltage in bipolar prostate electrosurgery should also eliminate the possibility of interference with all types of cardiac pacemakers. Differences in arrangement of active and passive electrodes allow distinction between devices: whether two loops (parallel or opposite), using the distal end of the resection loop, or using the working element of the resection shaft.

The common challenges faced by each of the systems are to reliably establish a cutting plasma corona preferentially at the distal active electrode, to minimize the time from foot-switch activation to plasma production (i.e. instantaneous fire-up), to maintain this under all cutting conditions, and to provide adequate hemostasis from both cut and coagulation modes.

The configuration and size of the active electrode for prostate resection and incision is unique for each of the commercially available systems (Figure 131.4). Although there are certain basic similarities (e.g. active electrode slightly thinner and separated from the thicker return electrode component by an insulator), there are differences in resectoscope size, and design of the electrode housing and coupling to the active and return cords. At the moment of fire-up by foot-pedal activation, if the activated component of the bipolar electrode is not in contact with the tissue, if the gap is too wide, or if there is insufficient power, current flow is simply dissipated by the large volume of electrolyte solution in a full bladder, and there is no effect. On the other hand, if the power/voltage spike is not high enough both to form and maintain the plasma vapor pocket, stuttered cutting will result, depending on the quality of tissue contact.

Gyrus-ACMI

As a result of these challenges, the initial PlasmaKinetic (PK) Gyrus system, which was the first to encounter some of the above difficulties, has been modified in recent years, culminating in the Gyrus SuperPulse® Generator. This newer device is preconfigured for

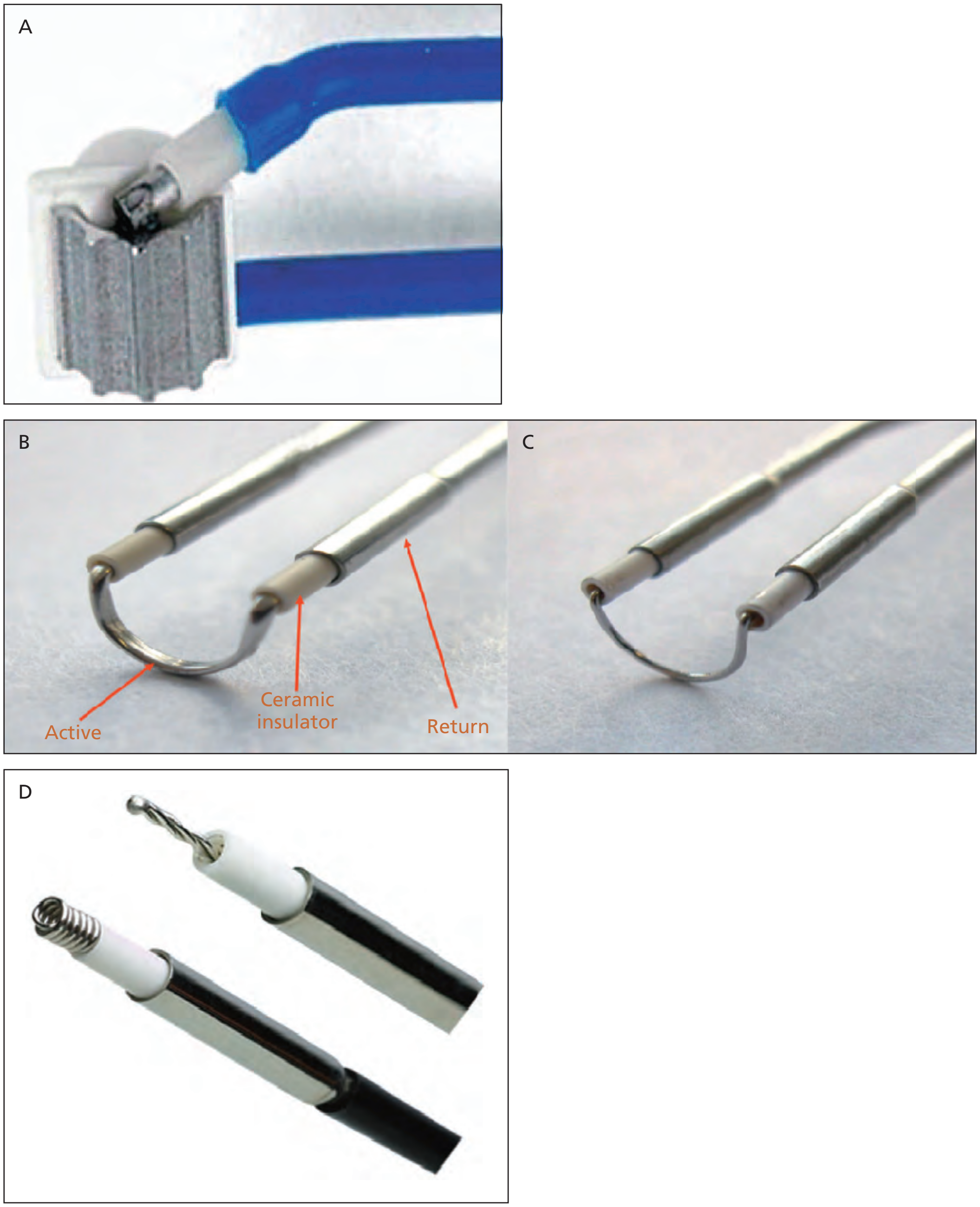

Figure 131.4 Bipolar electrode configurations of (A) Plasma V vaporization electrode (courtesy of Gyrus Medical, Maple Grove, MN, USA); (B) SuperSect thick and (C) SuperLoop thin resecting loops (courtesy of Gyrus Medical); (D) PlasmaCise thick and thin incision electrodes (courtesy of Gyrus Medical); (E) Vista Coblation resecting double loop (courtesy of ACMI Corporation, Southborough, MA, USA); (F) SurgMaster (courtesy of Olympus, Tokyo, Japan), single resecting loops (large, medium, small, and angled) and other electrodes; (G) Storz double resecting loop (© courtesy of Karl Storz, Tuttlingen, Germany); (H) Wolf bipolar electrodes (courtesy of Richard Wolf, Knittlingen, Germany).

maximal allowable current under low impedance conditions. However, the surgeon is able to choose between two sets of cut voltages, which are preset (represented by SP1 and SP2). The SuperPulse Generator is designed to recognize the active electrode and offers default settings that are optimal for a range of conditions at the tip [e.g. SP2 160, corresponding to a maximum voltage of 307 volts root mean square (Vrms) sinusoidal (434-V peak) and 160-W maximum average power]. While the original Gyrus device had the active and return electrodes on the same axis, separated by a ceramic insulator, the subsequent Plasmasect and PK systems retained the coaxial principle but redesigned the tissue contact points into loops, thus allowing resection of tissue.

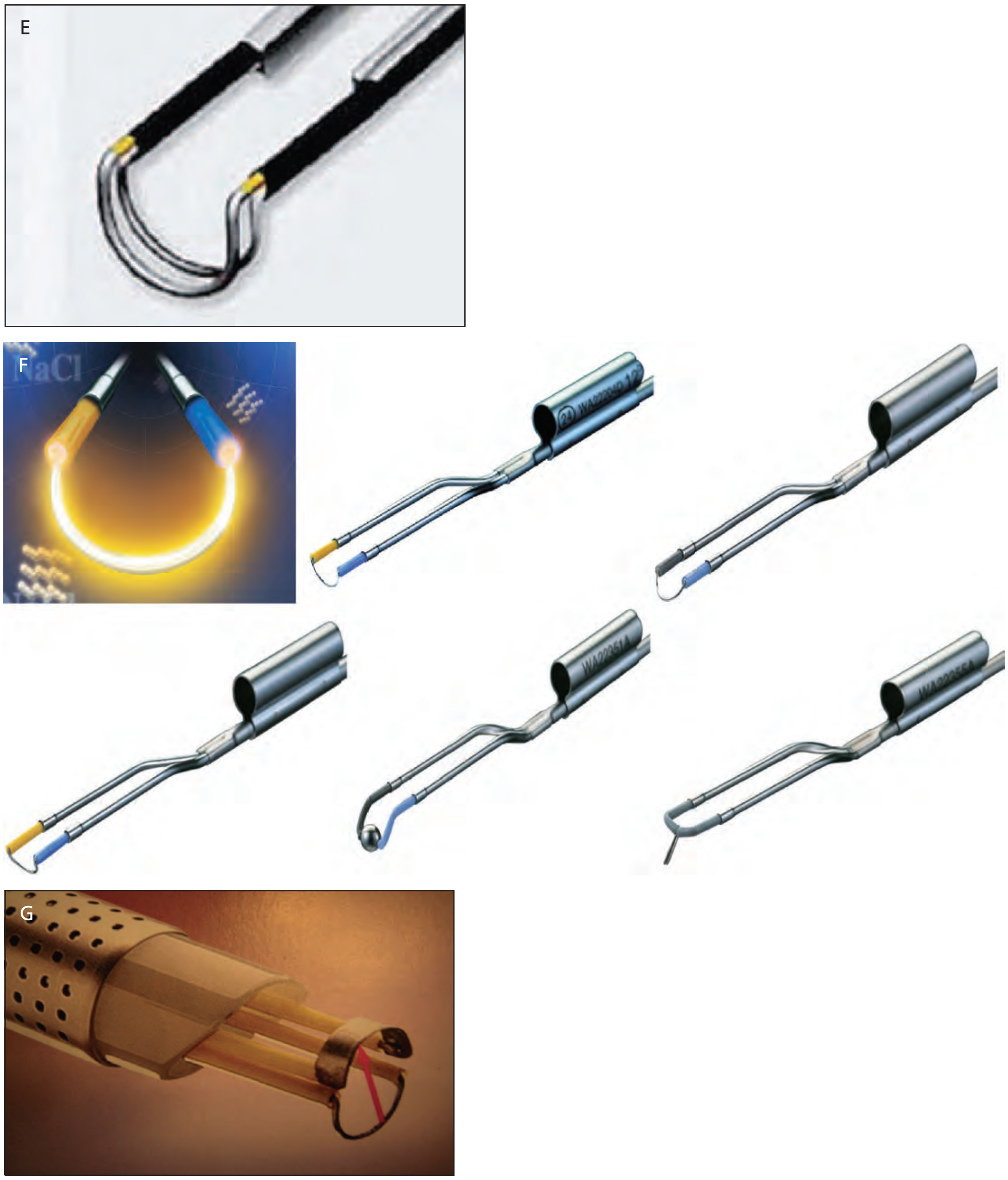

Figure 131.4 *Continued*

The SuperPulse Generator contains an energy reservoir facility in the form of a bank of internal capacitors. In this way, there is provision of sufficient voltage for both instant fire-up at the start of each cut and for power ride-through under challenging conditions of impedance. In this way, this manufacturer has resolved the problems of stuttered cutting that occurred with the previous generation of the device. The reservoir bank is quickly precharged before foot-pedal RF voltage initiation by the surgeon. Tests have shown that under high-flow and cold saline conditions, more power than normal is required to initiate and maintain plasma conditions at the active electrode tip. The capacitor reservoir can provide up to 4000 W of power for short periods (~10 ms), but only if the tip impedance is low enough.

At baseline, before RF voltage application, the impedance differential between bipolar active and return electrodes is between 23 and 60 ohm, depending on the saline temperature and the proximity of the active electrode to the tissue bed. At high power (4000 W) and low impedance (23 ohm), a voltage of close to 300 Vrms can be sustained by the SuperPulse Generator for long enough to allow saline immediately surrounding the active loop to be actively heated and reach boiling point

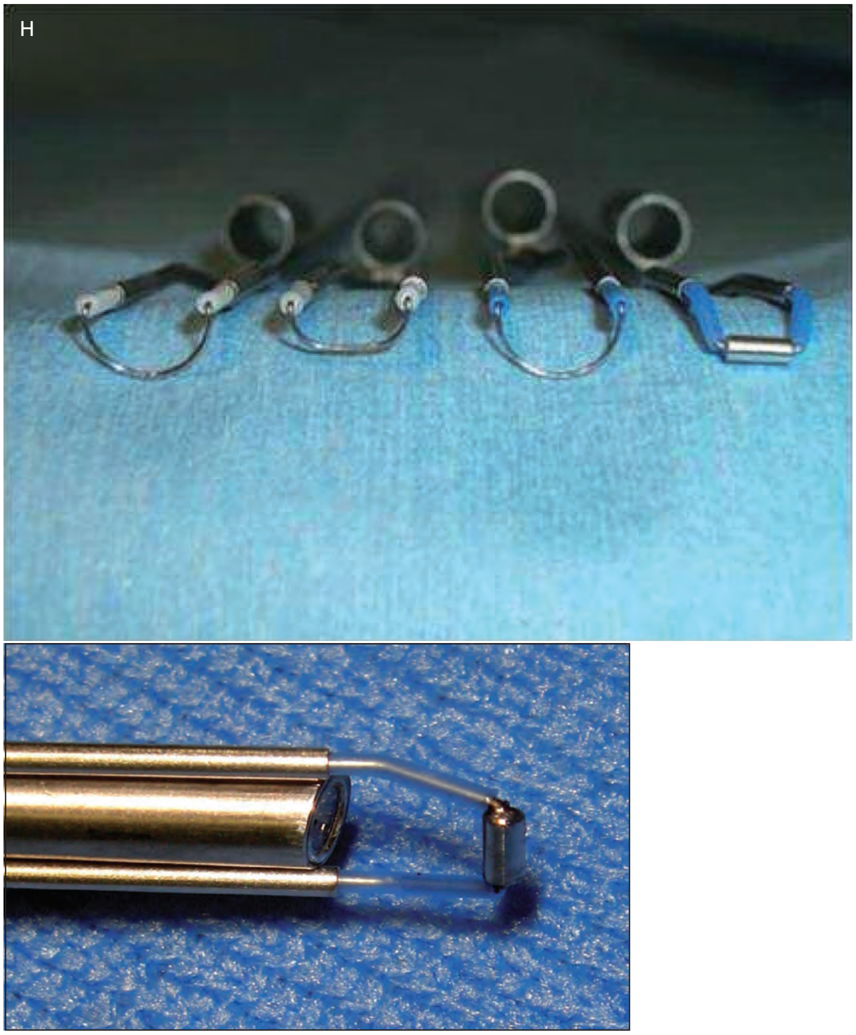

Figure 131.4 *Continued*

in a few milliseconds. This phenomenon is due to current crowding at the reduced surface area of this part of the active electrode, and it creates a nonequilibrium vapor pocket containing charged sodium ions.

Clinically, there is a precision tissue effect with minimal collateral damage, as the charged ions have only a short estimated range of 50–100 μm of penetration. The extent of the collateral tissue damage depends on resistive heating caused by any current flowing through the tissue, and by limited thermal transfer from the electrode sources. The end result is excellent localized cutting, with little in the way of the burnt smell traditionally associated with monopolar cutting. The depth of the surface coagulation is determined principally by the electrode configuration and by the system design, as well as by the technique used by the operator (time and pressure of contact). Coagulation has to take place with this technology at low peak voltage (in direct contrast to monopolar coagulation: 80–100 V for the PK system and 65–115 V for the Vista system), as higher peak voltages convert the liquid into a gaseous phase of higher impedance. This, in turn, changes impedance from a resistive to a capacitative mode, which reduces energy flow, reduces dissipated heat, and limits the final coagulation effect. Hence, longer contact times may be needed.

There are several electrodes available with the Gyrus system, including the SuperSect® Loop (with a wide surface area that helps to seal bleeding vessels, making it ideal for prostate resection) and the SuperLoop® (thinner, more traditional loop, making it ideal for bladder tumor resection); also, there are the PlasmaCut® and PlasmaCise® electrodes that have braided tips for treatment of urethral strictures and bladder neck stenoses. The resectoscope and electrode fittings are shown in Figure 131.5.

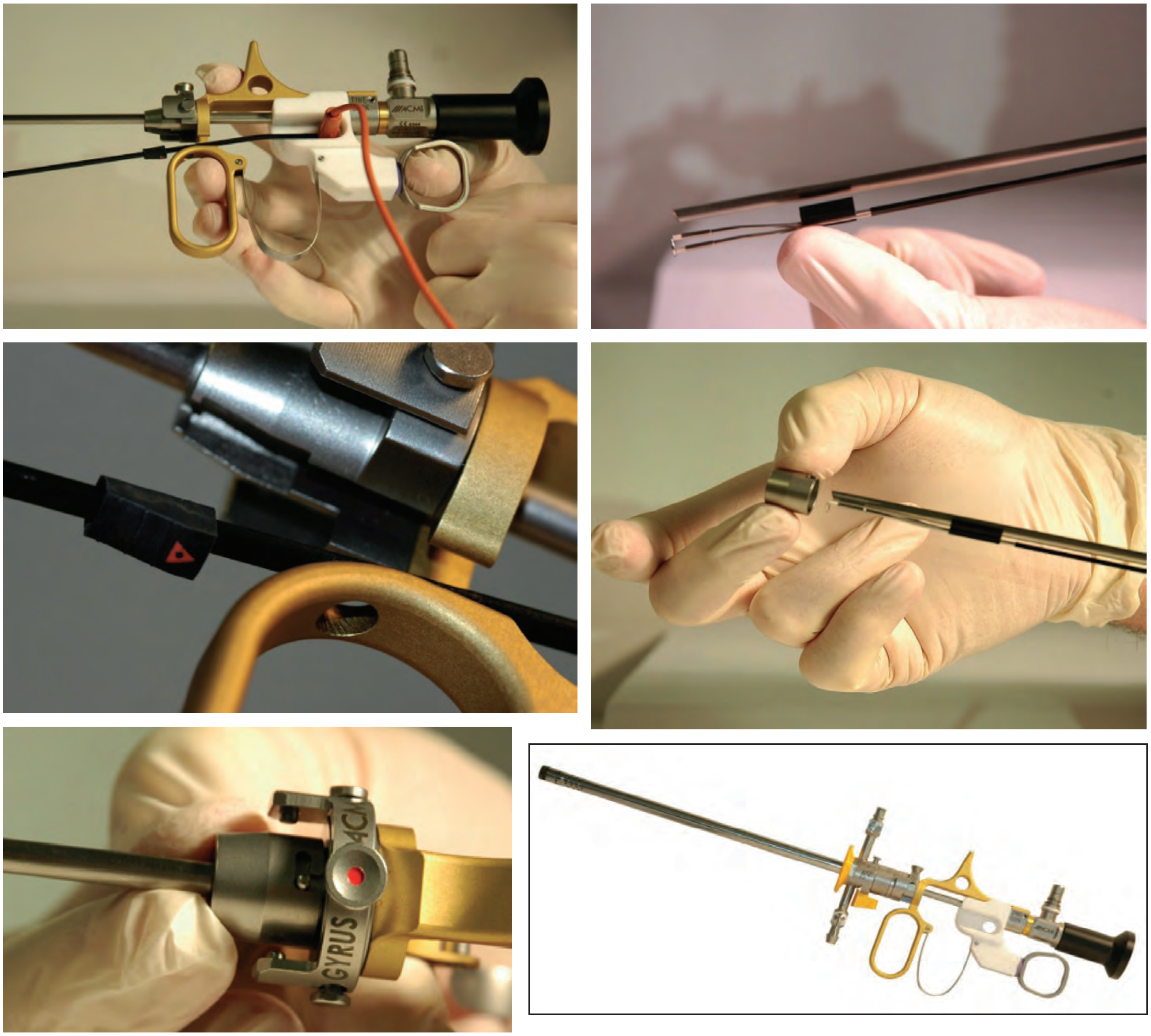

Figure 131.5 Electrodes and fitting of the Gyrus-ACMI resectoscope loop (courtesy of Gyrus Medical).

Olympus

The SurgMaster system uses a loop design similar to those developed by Gyrus, but the loops are of a slightly smaller diameter, thin-wire design, and separated by yellow insulating material from a thicker more bulbous return end. The resectoscope itself is 26F in size and has a working length of 194 mm. This design also permits current crowding at the thinner active loop to allow the plasma pockets to be formed. The current reaches the active portion of the loop from the generator through the white plastic housing in the bottom of the working element, while the return current flows through the return portion of the electrode in contact with the working element and then back to earth through a lead connected to the working element handle. Hence, part of the telescope housing of the working element is specially insulated to make it fit for this purpose, without compromising patient or operator safety by return current leakage. At the resectoscope tip, the electrode and telescope are separated from the metallic outer sheath by insulating material (Figure 131.6). The SurgMaster generator in the "TURis" (transurethral resection in saline) mode allows saline resection through two cutting modes (pure and blend with maximum power output of 320 W) and coagulation through two modes designated Coag. 1 (maximum 200 W) and Coag. 2 (maximum 80 W), though only in combination with the SurgMaster resectoscope. It also has a capability to produce a monopolar output for standard surgical and endosurgical use.

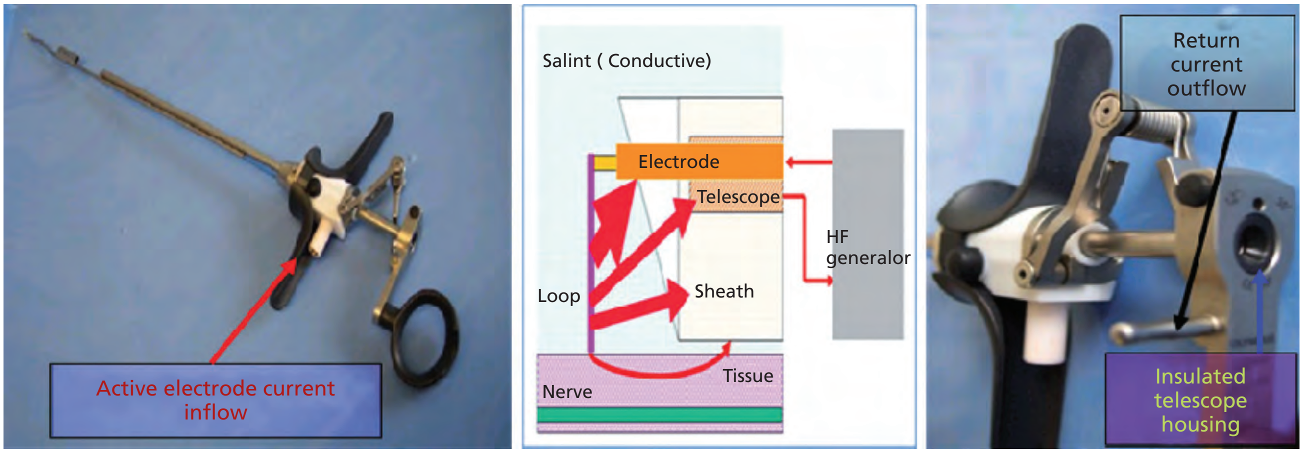
Active electrode current inflow
Salint (Conductive)
Electrode
Telescope
Loop
Sheath
HF generalor
Nerve
Tissue
Return current outflow
Insulated telescope housing

Figure 131.6 Design of active loop and working element for SurgMaster® resectoscope (courtesy of Olympus, Tokyo, Japan). HF, high frequency.

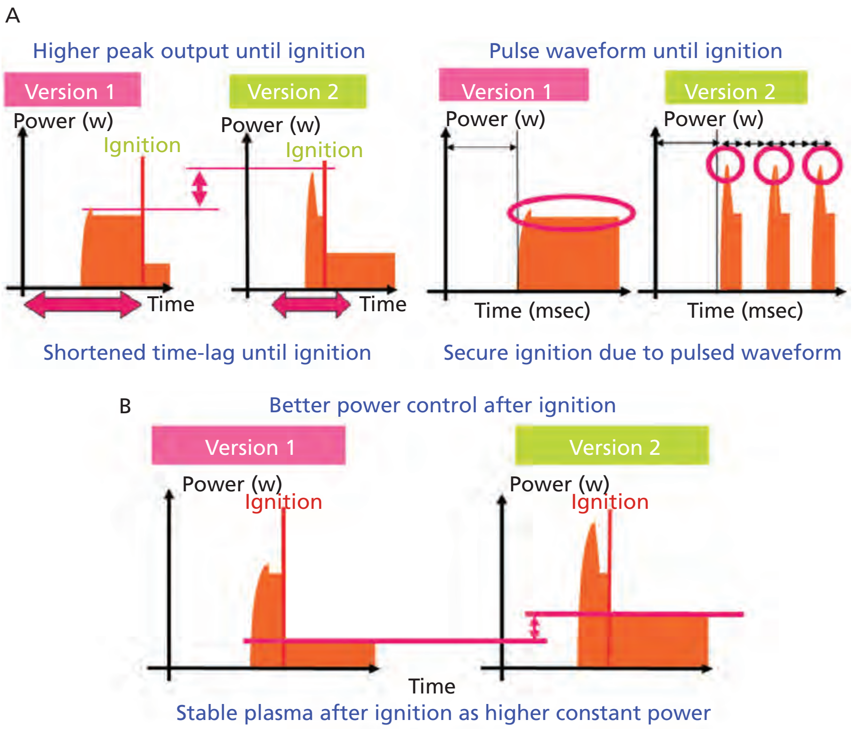

Figure 131.7 (A, B) TURis SurgMaster® second-generation generator modifications (courtesy of Olympus).

In the TURis system the active electrode is in the resection loop, while the return electrode is in the working element of the resectoscope; this has cost implications, since whereas the Gyrus coaxial electrode and ceramic insulator resulted in a PK loop costing approximately US$300, the corresponding cost for a TURis loop was US$60 [10]. The device may be set at 280 W for cutting and 100 W for coagulation. The second-generation of TURis devices can be compared to the first-generation devices in terms of higher peak output until ignition (but now with a shortened time lag until ignition), as well as a pulsed waveform output until ignition (Figure 131.7A); after ignition, the second-generation devices then also produce a more stable plasma, with higher constant power (Figure 131.7B). It is not known yet whether these changes in generator design will ultimately wear out thin loops quicker with prolonged use in larger glands.

Another recent modification is the new electrode designs, including a mushroom-shaped electrode

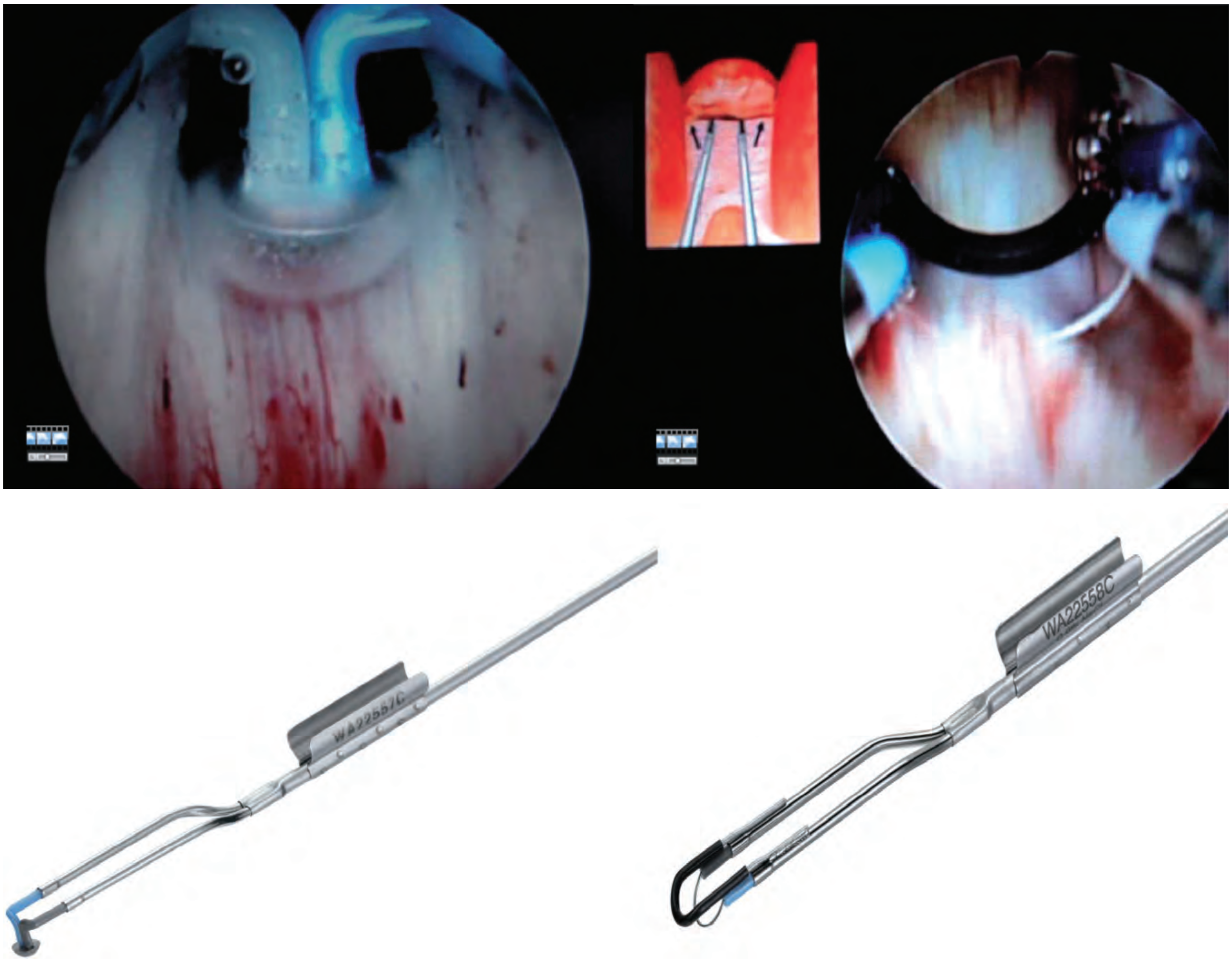

Figure 131.8 Mushroom-shaped button electrode and double-loop electrode for resection–enucleation (courtesy of Olympus, Tokyo, Japan).

(Figure 131.8), which permits vaporization of the prostate, with heat penetration up to a depth of 0.20 mm.

Enucleation of the prostate is now also feasible with the new double-loop electrode design (Figure 131.8), but unfortunately, this has the same downside as its laser equivalents in that it needs to be combined with adequate morcellation, which is still the main limiting factor for any enucleation technique.

Karl Storz

The Storz bipolar resection system was the third of the four commercially available systems. It consists of a classical double loop with a 5-mm diameter thin-wire active component and a flat thick bow loop bent in the opposite direction, which is the return component, with both loops mounted on the same axis of a dedicated resectoscope. It was found that a power setting of over 300 W was needed for *in vivo* cutting (compared to monopolar cutting, which can happen at 80 W). Furthermore, there could be a delay of almost 1 s until the loop became submerged in the tissue and reliable cutting occurred. Bleeding rates were lower than for monopolar diathermy, and the coagulation zone slightly deeper for the bipolar device. Electrical recordings suggested that using the standard generator, the 0.8-s delay in onset of bipolar cutting and inconsistency of cutting quality (as with many of its predecessors) were due to the time taken for the high current output at low impedance to produce the vapor pocket, and this, in turn, was critically dependent on electrode configuration, and generator design and function. Measurements taken during a single bipolar cut, which show the delay to actual cutting, followed by voltages of up to 450 V and power of up to 475 W under varying impedance conditions during actual cutting, support the need for a dedicated generator design with such devices, for it is likely that systems that do have difficulty initiating fire-up will have greater thermal spread in tissue at the point of RF initiation because the surgeon cannot move the loop until the vapor pocket and plasma have been (slowly) established [11].

Since this first-generation system, a second-generation system has been released by this manufacturer, extending the range of electrodes (Figure 131.9), which have been slightly reduced in size compared to the first generation. The Autocon®II 400 ESU has in addition to both standard bipolar and unipolar output modes, a newly added Resection box connected in series for saline bipolar procedures. It is designed to enable more effective power delivery in low impedance (saline) conditions by the addition of "Saline-C-Cut ++" and "Saline-Coag ++" modes. This system and electrodes are yet to be studied in the clinical setting.

Richard Wolf

The Wolf S(a)-Line system (Figure 131.10) (Richard Wolf, Knittlingen, Germany) was the last to appear commercially and has similarities in construction to the system from Olympus, with a compatible electrosurgical unit. There are sparse peer-reviewed published clinical data on this system at the time of writing.

Technique

Although there should be no problem with TUR syndrome with bipolar loop resection, urologists must adhere to the principle that there is no place for complacency as far as surgical technique is concerned. Hypervolemia and hypothermia from cold saline absorption through the resection fossa can still occur, leading to heart failure in elderly patients with cardiac comorbidity, so irrigant should still be warmed before use and the operator should empty the bladder periodically of accumulated irrigant (since inflow is usually greater than outflow, even with continuous flow resectoscope systems). Furthermore, regular emptying of the bladder helps to better reveal bleeding points so that they could be controlled in a timely fashion.

With regard to handling the resectoscope, Rassweiller *et al*. compared the standard monopolar device with the ACMI bipolar, Gyrus PK and Storz bipolar instruments, in terms of ease of connecting the electrode, initiation of cut, coagulation, and lifetime of the loop, and showed them to be broadly similar (Table 131.1) [12].

If, as is suggested by the studies of Wendt-Nordahl *et al.* [11], bipolar coagulation is shallower than monopolar coagulation with the Vista system, then it is likely that the incidence and duration of postoperative irritative symptoms (which are usually the result of an excessively coagulated tissue bed and delayed sloughing of this tissue, as was seen with Nd:YAG laser therapies in the past) could be reduced and shortened. Evidence to support this contention was provided by the study of Singh *et al.*, who performed a randomized controlled trial in 60 men comparing the Vista bipolar resection system versus a regular monopolar loop [13]. No difference was found in clinical outcome parameters, but irritative symptoms of postoperative dysuria in particular were less common with bipolar loop resection. The key remains whether all systems have a similar action on the tissue bed with regards to depth, given the design and generator variations from one system to another.

Outcomes of bipolar transurethral resection of the prostate

A recent meta-analysis of 16 RCTs comparing bipolar (704 patients) with monopolar TURP (702 patients, total 1406 patients) by Mamoulakis *et al*. has highlighted the challenge of analyzing heterogeneous data from different centers [14]. The studies included 10 PK trials, four TURis trials, and two Vista trials. The largest studies were from Turkey (120 in each arm [15]) and Belgium (approximately 120 in each arm [16]). Apart from the 4-year update on a prospective randomized RCT described by Autorino *et al*. [17], the length of follow-up from the other trials was rather limited, at a maximum of only 1 year.

Nevertheless, there appeared to be no statistically significant differences between bipolar and monopolar TURP in terms of short-term efficacy. With regard to safety, a number of factors were analyzed, including the incidence of TUR syndrome. Although the individual trials did not show a significant difference, a total of 13 cases of TUR syndrome were reported with monopolar TURP versus none with bipolar TURP. The authors proposed that 50 patients with bipolar TURP would need to be treated for there to be one less TUR syndrome episode, and 20 patients to prevent one less clot retention episode.

Also, there appeared to be no major difference in hemoglobin drop after either procedure, which seemed counterintuitive to the argument that bipolar TURP gives better hemostasis. Interestingly, in the accompanying editorial, it was pointed out by Reich that in his narrative experience (a view he felt was shared) that there was no tangible difference in hemostasis with this technique, possibly confirming the findings of the meta-analysis [18]. At the time of writing, a Swedish randomized study by Fagerstrom *et al.* of 202 patients,

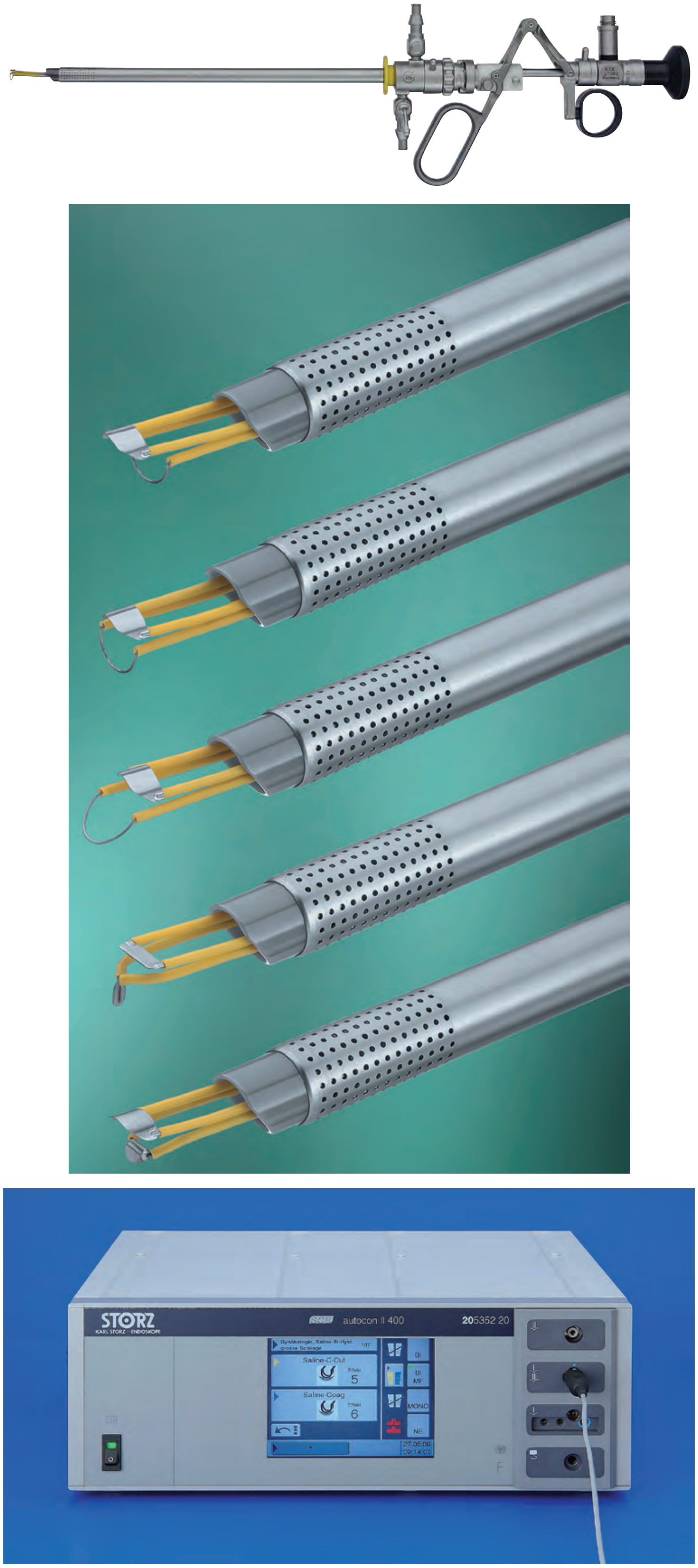
STORZ
KARL STORZ · ENDOSKOPE
autocon II 400
205352 20
Saline-C-Cut
5
Saline-Coag
6
MONO

Figure 131.9 Storz bipolar resection system: resectoscope, second-generation electrodes for resecting prostate and bladder, incision and vaporization, and Autocon® II 400 ESU Bipolar Saline Resection Box (© 2010 Photos courtesy of KARL STORZ Endoscopy-America, Inc.).

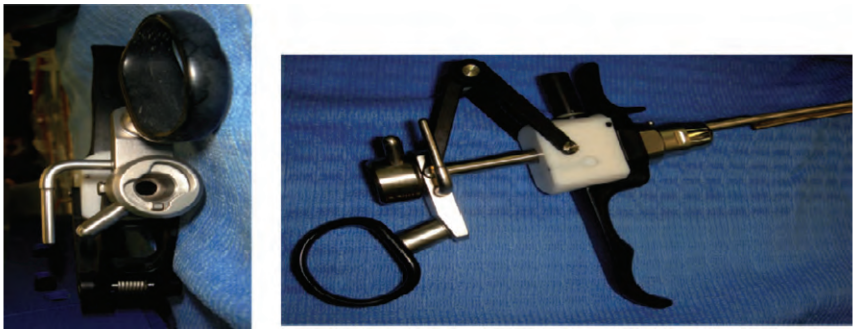

Figure 131.10 Wolf S(a)-Line bipolar resectoscope working element design (courtesy of Richard Wolf).

Table 131.1 Handling of bipolar resectoscopes compared to the monopolar device (modified from Rassweiller *et al*. [12]).

Feature	TURP mono	Gyrus PK	Storz bipolar	Olympus TURis
Size (F) of resectoscope	24	26	24	24
Connecting electrode	Easy	Easy	Easy	Easy
Starting cut	+++	+++	+++	+++
Resection speed	+++	+++	+++	+++
Fine resection	+++	++	+++	++
Coagulation	+++	+++	+++	+++
Loop lifetime	+++	+++	++	+++

undergoing bipolar TURis or monopolar TURP, reported a 34% lower blood loss (235 vs 350 mL, $P < .001$) in the bipolar arm [19].

The rate of postoperative urethral stricture was also reviewed in the meta-analysis of Mamoulakis *et al*. [14]. While there was no statistically significant difference between monopolar TURP and either Vista, Gyrus or TURis procedures, single studies have mentioned differences. For example, Ho *et al*. reported three urethral strictures in 48 patients in the bipolar arm of TURis compared to one in 52 patients in the monopolar arm [10]. It has been speculated that this may reflect the outer sheath of the resectoscope acting as the return electrode, thus theoretically increasing urethral mucosal damage from localized small contact points. The theoretically possible localized current pathways from bipolar/quasi-bipolar energy, particularly if they are altered by uneven application or distribution of lubricant gel on the instrument surface, are illustrated in Figure 131.11, as postulated by Faul and Fastenmeier [20]. A large series of 1000 patients undergoing TURis procedures (both prostate resections and bladder tumor resections) reported a urethral stricture rate of 2.9% after bipolar TURP [21]. This compares favorably with published rates for monopolar TURP; interestingly, Puppo *et al*. mentioned performing urethrotomy prior to resection in cases "with an inappropriate relationship between the size of the instrument and the diameter of the external urethral meatus" [21]. An earlier study found a lower rate of urethral stricture at up to 6 months in TURP patients undergoing an initial Otis urethrotomy compared to no urethrotomy [22]. Other factors that may contribute to stricture formation include the resectoscope diameter (e.g. 27F for Gyrus PK), size and material of catheters, and higher ablative energy used, though overall there appears to be no significant difference between bipolar/quasi-bipolar and standard TURP.

Similarly, no difference was reported in the risk of postoperative acute retention in the meta-analysis [14]. The duration of postoperative catheterization varied between the studies, but this actually reflects variation in local policy (not protocol driven) and is therefore not necessarily a valid independent endpoint for comparisons. Retrograde ejaculation rates were similar for both monopolar and bipolar technology, as may be expected. A randomized controlled trial to assess incidence of postoperative erectile dysfunction is awaited, grouping small, medium, and large glands separately for analysis, since bipolar energy would theoretically produce less transmission of heat energy, thereby causing less damage to the adjacent nerve bundle.

While it is possibly most relevant to compare the use of these cauterization techniques, it would also be topical to compare bipolar TURP with the other modality proposed to produce less blood loss, namely laser techniques. Several laser technologies are now available, but broadly speaking, there are ablative techniques [e.g. KTP (GreenLight™) or diode] or ablative/enucleation/resection techniques (holmium or thulium). With the advent of the mushroom (or button) electrodes that allow vaporization using TURis, a true comparison with an ablative laser is now feasible. Similarly, enucleation techniques can now be compared between bipolar resection and the holmium laser, with morcellation techniques now available. Some argue that future studies

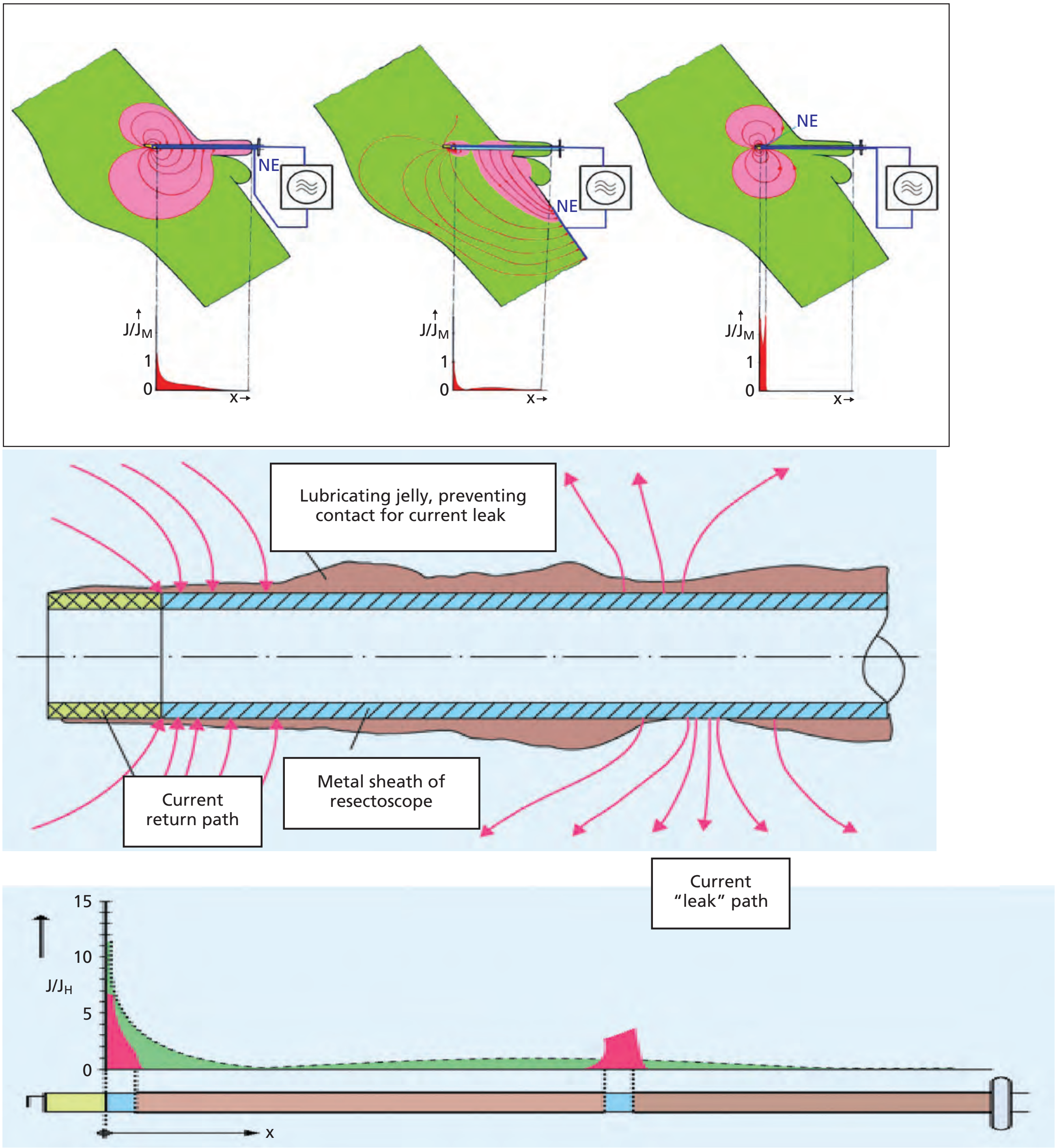
NE
J/J_M
1
0
x→
NE
J/J_M
1
0
x→
NE
J/J_M
1
0
x→
Lubricating jelly, preventing contact for current leak
Current return path
Metal sheath of resectoscope
Current "leak" path
15
10
J/J_H
5
0
x

Figure 131.11 Quasi-bipolar, monopolar, and bipolar respective possible electric current flows and possible differences in urethral contact with resectoscope depending on surface lubricant inequalities [20]. The areas with inadequate lubricant cover theoretically could permit conduction of current from small localized contact areas away from the resectoscope sheath to the adjacent urethra, possibly increasing the chance of thermal damage to adjacent structures. (From Faul and Fastenmeier [20], with permission.)

should compare bipolar with laser technology (rather than with monopolar), and multicenter trials are eagerly awaited in these areas.

Training and morbidity

Bipolar TURP should allow more time for teaching and training urology residents in how to resect prostatic adenomatous tissue without compromising patient safety, for all preliminary studies have shown the risk of hyponatremia to be uniformly low. This is a welcome advantage for the novice trainee, freed of the shackles of time constraint to a large degree, both for the resection phase and also for the coagulation phase of the operation. This is particularly important when the use of TURP has been declining, and a large proportion of patients requiring surgery are either in acute or chronic retention or have large vascular glands (as combination medical therapy with alpha-blockers and cytoreductive 5-α reductase enzyme inhibitors does not have widespread penetration into routine clinical practice due to cost).

With regard to the technique, only minor changes are needed, and for urologists already proficient in performing monopolar TURP, as bipolar systems are almost identical with regard to equipment, the learning curve should be almost negligible. At this time, it is not known whether the risk of capsular perforation and subsequent impotence will be reduced until this issue is formally studied. Hemostasis seems to be slightly improved at the resected tissue surface, but deep coagulation is limited, and care must still be taken to avoid opening large venous sinusoids.

One of the concerns that exists for many transurethral bipolar resection systems, as with monopolar electrosurgery, is the potential for urethral and bladder neck stricture formation postoperatively. Although reports on bladder neck strictures for the bipolar systems are sparse, the incidence of urethral strictures in the study by Tefekli *et al.* at 6.1% (vs 2.1% for the monopolar TURP arm) is of concern [23]. Etiologically, there are many possible reasons for the higher stricture rate in this study and that by Ho *et al*. [10]. These include larger resectoscope diameter (27F), especially if the urethra is not adequately predilated before passage of the resectoscope, higher incident power (even if in short bursts), electrode re-use, and if a larger prostate is tackled or one is tackled by a relative novice, a long operating time. Of interest is the paper from Morishita *et al.*, which, in 1992, indicated that urethral stricture formation post TURP may be closely related to electrical resistance and current leakage of appliances [24]. They investigated old and new monopolar and bipolar loops and found that the new unused bipolar loops had a low electrical resistance of 0.5–0.6 ohm, increasing with multiple use (for at least 60-min durations) to 1–115 ohm (mean 26.4 ohm), while none showed current leakage. In comparison, all monopolar loops exhibited current leakage after first use and showed relatively high resistance. These data indicate the superior durability of bipolar loops compared to their monopolar counterparts, and if reproduced in currently available bipolar loops, confirm their superior safety over their monopolar counterparts. But clearly, there is a need to develop bipolar continuous-flow resectoscopes smaller than 27F in diameter in the not-too-distant future.

Transitional cell tumor resection

Bipolar systems are being used to resect transitional cell tumors in the bladder (and possibly increasingly so in the renal pelvis in due course). Less char will mean better potential histologic analysis, but use of an isotonic solution means that loose cancer cells from higher-grade bladder tumors will not be lysed as they are in a bladder full of hypotonic irrigant such as sterile water, leaving greater theoretical possibility of seeding viable cancer cells (though this has not been substantiated experimentally to date). Another potential advantage is reduced stimulation of the obturator nerve, and thereby less risk of inadvertent bladder perforation. Futhermore, bipolar resection is a useful tool for resecting tumors in patients with a cardiac pacemaker. There have been recent suggested modifications in electrode design for bladder tumor resection, and these may be matched with availability of bipolar electrodes, including the possibilities that accompany the development of thick and thin electrodes.

Cost

This issue has not been studied in detail. A financial analysis by Ruiz-Deya *et al.* showed the cost of bipolar saline TURP to be 10.56% less than that of conventional monopolar TURP [25]. This translated into a cost saving of US$1138 per patient in their institution, but they did not take into account the cost of purchasing a new dedicated generator, a new resectoscope, or at least a new working element, active electrodes that are more than 8–10 times the cost of a regular loop, not to mention a longer possible operating room time (which could be offset by lower morbidity). Furthermore, there is as yet no good sense of loop durability in long resections, and cost will increase if more than one loop has to be used in larger glands. Thinner loops may also be damaged or deformed by repeated contact with prostatic concretions of the variety that are sometimes encountered at the junction between transition and peripheral zones.

On the other hand, costs may be lowered in future through multispecialty use of the generator (in dermatologic, ENT, orthopedic, and gynecologic procedures), as well as its use in laparoscopic surgery, and will certainly go a long way to improving both its attractiveness and affordability throughout the developed world.

Conclusions

Transurethral bipolar electrosurgical vaporization and resection systems undoubtedly have future potential for a variety of reasons outlined in this chapter, particularly at a time when urologists may be tackling larger prostates endoscopically, given the dominance of the monotherapy medical treatment paradigm of the last decade or so. In the face of stiff competition from higher powered lasers (both holmium and KTP), whether this potential is bright, making it an indispensable tool in the prostate kitchen of tomorrow, or just a passing fad like so many other technologies that have failed to endure, will depend on mass acceptance of the technique in the established urologic workplace and particularly in training centers that will nurture the urologic surgeon of tomorrow. In order to achieve this, the cost comparisons and outcomes in appropriately designed larger multicenter studies, where bipolar loop resection is pitted against the enduring gold standard of monopolar resection and new challengers from the laser arena, must be forthcoming to establish a high-quality solid evidence base that will ultimately drive registration and reimbursement, without which no new technology can endure.

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CHAPTER 132

Monopolar Energy

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Monopolar transurethral resection of the prostate

Transurethral resection of the prostate (TURP) has been the gold standard in surgical management of patients with benign prostatic hyperplasia (BPH). The procedure has withstood the test of time, while many new, self-proclaimed "superior" procedures have failed to last in an era of procedure frenzy. The place of conventional TURP using monopolar energy has recently come under heavy scrutiny with the emergence of bipolar systems. The underlying principles of both monopolar and bipolar electrosurgical systems are similar, but the manner in which the current returns to the generator is different. However, until the long-term safety profile of the latter approach becomes established, monopolar TURP will continue to be an important tool in the therapeutic armamentarium of urologists dealing with BPH patients.

History

Electrosurgery had its beginning in 1882 when d'Arsonval found that high-frequency alternating current when passed through the body caused heating without muscle and nerve stimulation [1]. Young (1909) improved the endoscopic application of electrosurgery by using a fenestrated tube in place of an inner cutting tubular knife for the cold punch operation for prostatectomy [2]. This innovation allowed water to be infused between the electrode and the sheath, thereby improving vision and cooling the instrument. Edwin Beer (1910) is credited with being the first to make use of electrosurgery endoscopically by placing an electrode through a Nitze cystoscope to remove tumors of the bladder neck [3]. Stevens and Bugbee performed the first electrosurgical endoscopic incision of the prostate in 1913 [4, 5].

The development of the spark gap generator was a landmark invention which came into existence with the pioneering efforts of Liebel and Bovie (1924) [6]. This generator was able to produce both cutting and coagulating waveforms, which greatly facilitated hemostasis while resecting the prostate. Shortly after this invention, Stern (1926) developed the early resectoscope using a cutting loop consisting of a small ring of tungsten wire of approximately 0.5 cm in diameter [7]. The loop was placed at right angles to the end of an insulated shaft and was connected such that the loop could be made to slide easily. The radiofrequency current was then delivered continuously under water to excise prostate tissue. However, securing hemostasis was still an important issue. Davis, by using the Bovie generator, not only overcame this problem, but also became the first to use it for excision of large amounts of prostate tissue. Joseph McCarthy (1932) subsequently developed the McCarthy resectoscope, which bears significant resemblance to the modern resectoscopes. The invention of rod–lens optical system by Harold H. Hopkins (1959) and the addition of fiberoptic light transmission by Karl Storz (1960) marked further breakthroughs in modern endoscopy [8]. Since then, several refinements in instruments and technique have been made by outstanding urologists, but the basic principles have remained the same.

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Electrosurgical basis of transurethral resection of the prostate

The entire concept of TURP (monopolar or bipolar) is based on the basic principles of electrosurgery. Ablation of the prostate is achieved by employing alternating current with wavelengths in the radiofrequency range. The standard alternating current, with frequencies in the 60-Hz range, is unsafe for use in this setting as it subjects the patient to the risk of excessive neuromuscular stimulation, leading to tonic–clonic contractions with rhabdomyolysis and cardiac arrhythmias. The role of an electrosurgical generator is to increase the frequency of this current to over 200 kHz, because at all frequencies above 100 kHz current can pass through the body with minimal neuromuscular stimulation and no risk of electrocution.

While using a monopolar system for TURP, the active electrode (cutting loop) is placed in contact with the prostate tissue. Inside the resectoscope, the electrical connection from the generator to the cutting loop is carefully insulated. When activated, the generator produces a high-frequency voltage which drives a high-frequency current through the patient. The current passes from the small active electrode (cutting loop) at the tissue interface, through the patient to a proportionately larger indifferent electrode, and subsequently back to the generator (Figure 132.1). Thus, in a monopolar TURP, the patient is part of the system. Alterations in the frequency of oscillation and wave form alter the quality of coagulation and cutting.

The current flowing through the patient heats the tissue in contact with the loop, the heat generated being proportional to the current density (current flowing per unit area). The current density is high only in the tissue neighboring the current loop, leading to vaporization of the fluid in the cells near the loop, which can be moved through the tissue almost without any mechanical force.

Types of current waveforms

The basic function of an electrosurgical unit is to fulgurate or coagulate tissue by use of low-frequency current and the incision of tissue with high-frequency current. Depending on the characteristics of the generator, a variety of current waveforms can be produced. The individual settings are governed by the machine and requirements of the surgical procedure. The historical terms coagulation and cutting waveform can be misleading as low-power settings in the cut mode produce excellent contact coagulation, while high-power settings in the coagulation mode will produce a cutting action.

Cutting waveform

Cutting current uses a pure, nonmodulated sinusoidal waveform (Figure 132.2). Electrosurgical cutting requires the generation of small arcs from the electrode to the tissue, which occur twice during each cycle at the maximum and minimum voltage of the sine wave. This implies that the frequency of these arcs will be double the frequency of the sine waves produced by the generator,

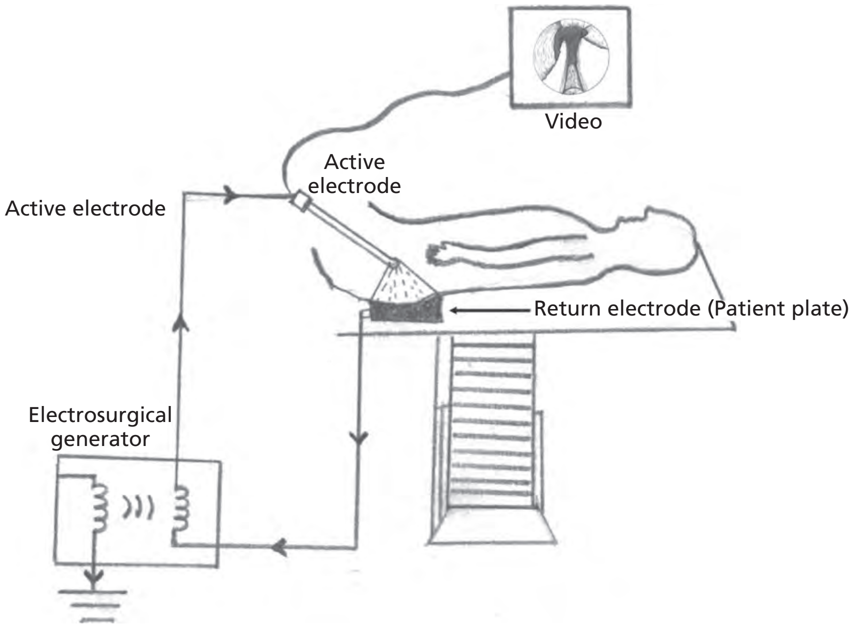

Figure 132.1 Monopolar circuit.

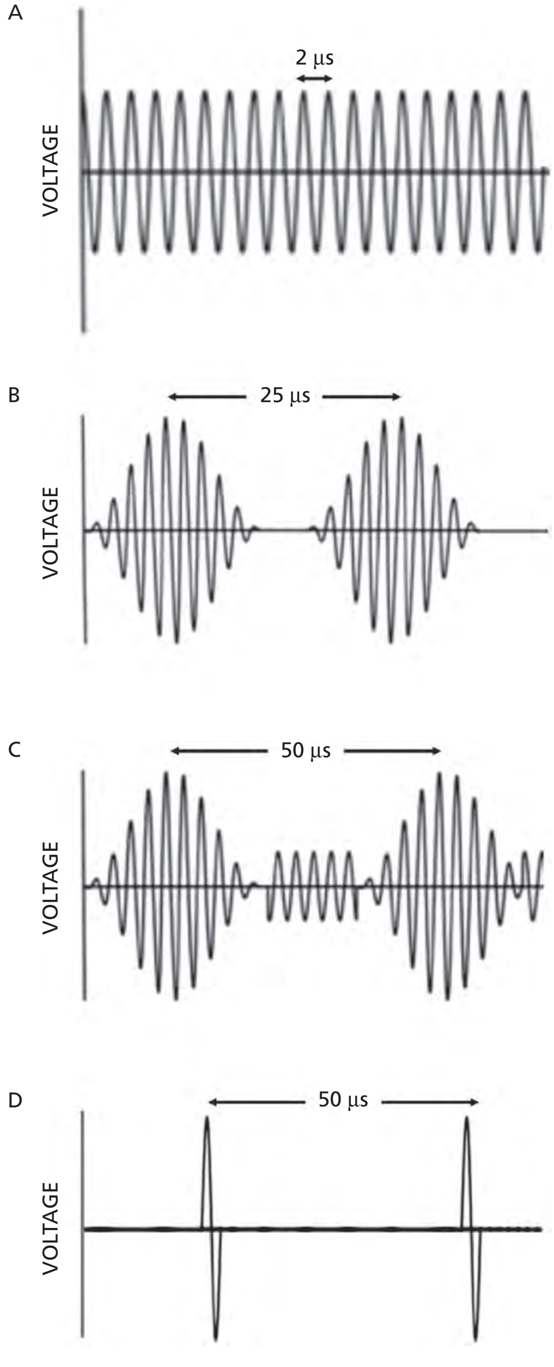

Figure 132.2 Waveforms. (A) Cutting current; (B) coagulating current; (C) blended current; (D) spray coagulation.

thereby facilitating a smooth cutting action without extensive thermal damage. This waveform achieves a higher average power when compared with any other alternating waveform of equal peak voltage (>500 V), allowing the voltage to be limited when compared with coagulation current. It is important to remember that the described cutting effect depends only on the magnitude of the current density, not on the frequency of the current. In general, cutting is produced by high tissue temperatures (>100° C), whereas coagulation is produced by tissue heating between 70° C and 100° C.

While performing TURP, a higher setting for the cutting current increases greatly the efficiency of the cut, while adding little to the danger of the procedure. On the other hand, too much cutting current produces a noticeable blue flame between the electrode and the tissue, which should be avoided. In general, small fibrous glands or bladder neck contractures are best treated by using a small-caliber loop with a high-intensity cutting current.

Coagulation waveform

Coagulation current is a highly dampened current characterized by extensive wave modulation in which the generator supplies current for less than 50% of the activation time. This produces intermittent bursts of damped sine waves of high peak voltages, up to 10 000 V (Figure 132.2). When employed, with the active electrode in contact with the tissue, these peak voltages result in high tissue temperatures, and hence significant thermal destruction, making this type of current particularly suited for the coagulation of bleeding vessels. Therefore, when this type of current is used in TURP, the intensity should be as low as will reasonably coagulate the tissue, and the time of application should be as short as possible.

Blended waveform

Blended currents are actually a combination of the above two waveforms, created by modulating a second, lower frequency, higher amplitude sine wave with the sine wave from the cutting generator, producing a higher peak-to-peak voltage. This waveform typically supplies current for only 50–80% of the activation period. The new waveform is then delivered in intermittent bursts at a rate determined by the settings of the electrosurgical generator (Figure 132.2). Blended currents allow the surgeon to cleanly divide tissue while maintaining a variable degree of hemostasis, depending on the amount of coagulating current used. Because more vascular glands have higher moisture content, this type of tissue is best resected using a blended current to maximize cutting and coagulation properties.

Spray coagulation waveform

This waveform is highly intermittent, with the generator supplying current for only 5% of the activation time (Figure 132.2). It is also high voltage (up to 10 kV) to produce long sparks between electrode and tissue. Operating in this mode, the active electrode does not touch the tissue, but instead, the high voltage causes air ionization and sparking. This mode uses relatively low current output (approximately 0.1 A) and thus leads to a thin layer of tissue necrosis with little depth of thermal damage.

Irrigation fluids

A hypo-osmolar irrigation fluid (1.5% glycine) is used that is nonconducting and not too rapidly absorbed. Despite having an osmolality of 200 mOsm/kg, it has played a role in reducing the risk of hemolysis and death by more than 50% from the days when distilled water was used for irrigation [9]. A variety of other electrically nonconducting irrigation fluids like 5% dextrose, 3% mannitol, and 3% sorbitol have also been used. Normal saline is not suitable for monopolar TURP as it may prevent the creation of a cutting arc because of its conductivity.

Indications for transurethral resection of the prostate

In 1989, the American Urological Association (AUA) initiated the Guideline Panel for Diagnosis and Management of BPH, which was later taken over by the Agency for Health Care Policy and Research (AHCPR) [10]. The panel subsequently recommended the AUA-7 Symptom Index for formal assessment of a patient's symptoms. The current indications for performing TURP are listed in Table 132.1.

Preoperative evaluation

Patient assessment

As most patients undergoing TURP are elderly, assessment of the renal, cardiac, pulmonary, and general physiologic status is of paramount importance because major derangements in these vital organs are important predictors of postoperative outcome. In addition to routine blood investigations, including hemoglobin, complete and differential blood counts, blood sugar, prothrombin time, and partial thromboplastin time, renal function tests (including serum creatinine and blood urea nitrogen) should be obtained from all the patients. Surgery should be postponed and catheter drainage done in patients with impaired renal function due to obstructive uropathy. Such an approach allows maximum possible improvement in renal function before the patient is taken up for surgery. An ultrasound abdomen with special emphasis on the kidney, ureter, and bladder (KUB) region should be obtained to assess the prostate size and postvoid residual volume (PVR). In patients who have not been catheterized, uroflowmetry is considered the single best noninvasive test to detect lower urinary tract obstruction. Pressure flow studies should only be done when the diagnosis is unclear. A prior cystoscopic assessment is generally not necessary and it can be done at the time of the procedure.

Table 132.1 Current indications for transurethral resection of the prostate.

Moderate (8–19)-to-severe (20–35) lower urinary tract symptoms (LUTS) not responding to medical treatment
Refractory urinary retention with at least one failed attempt at catheter removal
Chronic retention with back pressure changes, leading to: • Hydronephrosis • Renal insufficiency
Complications of benign prostatic hyperplasia (BPH), including: • Recurrent urinary tract infection • Recurrent gross hematuria • Bladder diverticula • Bladder stones

Perioperative antibiotics

Patients with evidence of infection should be treated prior to the planned procedure. Although the impact of prophylactic antibiotics in reducing postoperative infection was refuted by some authors, most of the available literature supports their beneficial role [11–16]. The antibiotic should cover both Gram-positive and Gram-negative organisms. Patients with an indwelling catheter are at a higher risk, even if no preoperative evidence of infection is detected. It is our practice to routinely administer a single intravenous dose of a broad-spectrum prophylactic antimicrobial 1 h before the procedure. The patient is subsequently continued on oral antibiotics until they are catheter free.

Anesthesia

The choice of anesthetic should be individualized, and the procedure can be performed under spinal epidural or general anesthesia with similar results [17–19]. Small volume glands (<40 g) can also be resected under local anesthesia, especially when associated major comorbidities are present [20, 21].

Surgical technique

The patient is placed in the modified lithotomy position. Care is taken to avoid overextension at the hip joint, and adequate padding is used for bony prominences.

Cystourethroscopy, if not done beforehand, is done as the first step to assess the distal urethra, position of verumontanum, size and configuration of the prostate, bladder neck, urinary bladder, and both ureteric orifices. In case of urethral narrowing, urethral dilators are used to dilate it to 28F. Sometimes, internal urethrotomy may be required to accomplish this. Meatal dilatation or dorsal meatotomy (using a curved blade or Otis urethrotome) is done if the meatus is narrow.

The resection technique may vary according to the size or configuration of the prostate, but should be based on an orderly plan. There are several different surgical techniques described for TURP adenoma; however, the principle remains the same, i.e. step-by-step resection and coagulation of each quadrant of prostatic lobes (Figures 132.3 and 132.4). Each operator is expected to familiarize themselves with any one approach which they are comfortable with, and then to master it with experience. A commonly used approach,

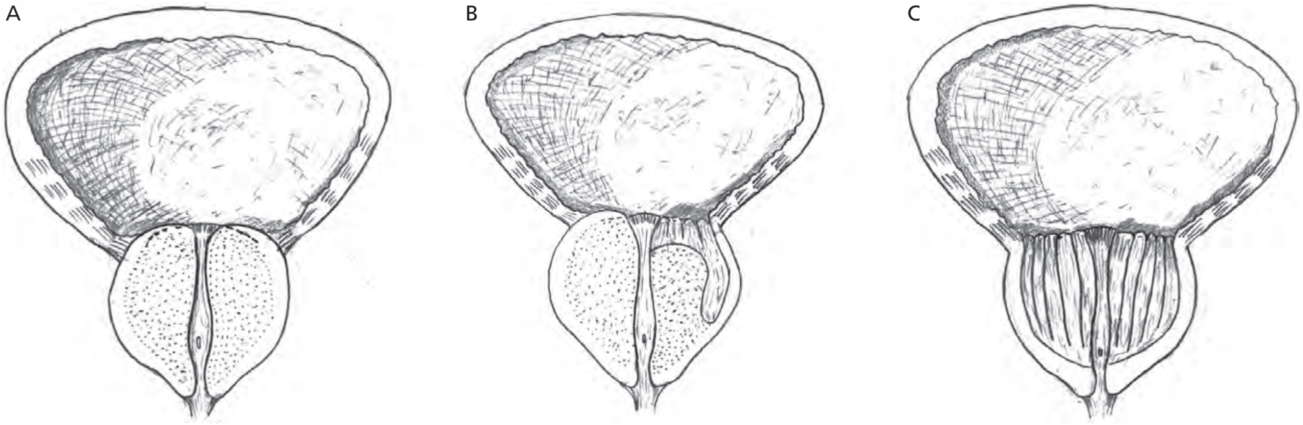

Figure 132.3 (A–C) Stages of transurethral resection of the prostate: coronal representation.

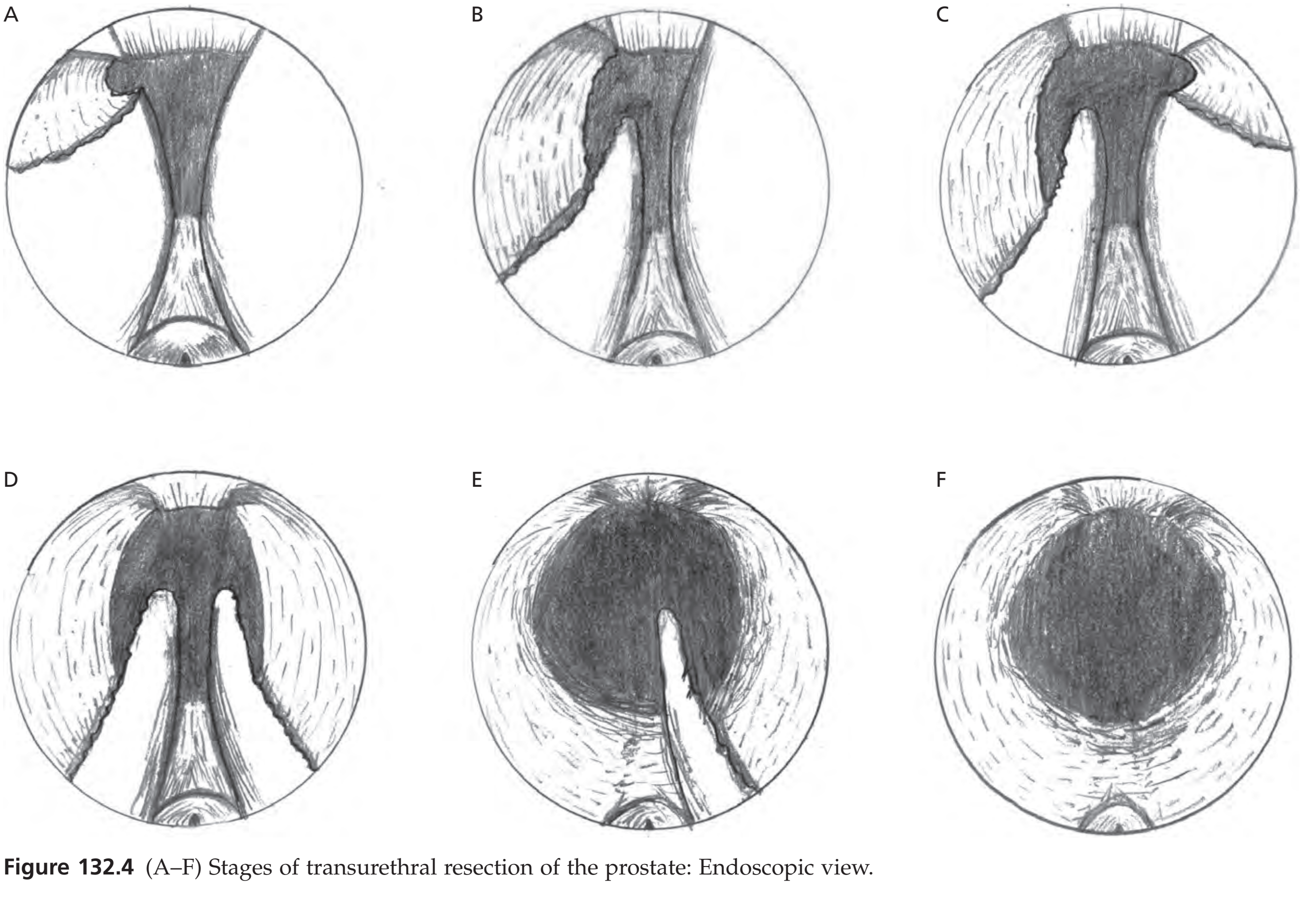

Figure 132.4 (A–F) Stages of transurethral resection of the prostate: Endoscopic view.

popularized by Nesbit, utilizes the principle of resecting anteriorly first so that the adenomatous tissue drops down, allowing the surgeon to resect from the top downwards rather than from the floor upwards.

A 24 or 26F size resctoscope, the continuous irrigation variety (Iglesias), is the most commonly employed equipment these days. The resectoscope is placed at the level of the verumontanum and the adenoma is resected in quadrants. Resection begins at 12 o'clock at the bladder neck, and is then carried down anticlockwise to the 9 o'clock position in a stepwise fashion to a depth where circular fibers of the bladder neck become visible. The resection is carried down to the surgical capsule, which is recognized as a rather fibrous structure compared with the granular appearance of the prostatic adenoma. The other anterior quadrant, from 12 to 3 'o'clock, is next resected clockwise.

Resection of the anterior quadrants results in the lateral lobes falling towards the floor. Resection of right lateral lobe is started at approximately the 9 o'clock position and continued in an anticlockwise fashion. The posterior portion on the floor of the prostatic fossa is resected. The resection is carried to the right side of the verumontanum. For the left lobe, a similar procedure is started at approximately 3 o'clock and carried clockwise to the left side of the verumontanum. As the lower two quadrants in the floor of the prostate are resected, the capsule fibers become less distinct. After completion of the lateral lobes, the tissue at 6 o'clock, including the median lobe if present, can then be resected up to the verumontanum. Care must be taken not to resect too deeply in the region of the posterior aspect of the vesical neck to prevent undermining of the trigone.

Large adenomas can be resected using "'encirclement," a modification of the above-mentioned technique. During resection of the lateral lobes, a groove is created between the bulk of adenoma tissue and the surgical capsule by working the resectoscope loop along the capsule, allowing the lobe to fall to the floor. The loop works somewhat like the finger of the operating surgeon in the open transvesical prostatectomy, separating the lobe from the surgical capsule of prostate. The procedure is done first on one side and then on the other side. Finally, the remaining bulk of tissue on the floor, which by now is mostly devascularized, can be resected quickly to complete the procedure.

Another variation of the technique, popularized by Blandy, starts with resection of the floor at the 6 o'clock position, including the median lobe if present. This is followed by resection of each lateral lobe from the 12 'o'clock down to the 6 'o'clock position in the standard fashion. The advantage of this approach is to establish the tissue planes and landmarks at the beginning of the operation. This approach can be especially useful in prostates with a large median lobe.

Towards the end, the apical portion of the lobe remains, which is resected last. Care must be taken to avoid extending the resection beyond the level of veru to protect the external sphincter mechanism, which lies just distal to it. The most common area of damage to the external sphincter is at the 12 o'clock position. Thus, care must be taken as the 12 o'clock position is approached. The resection, especially the apical portion, may be performed with a finger in the rectum, for which a rectal shield can be put in place at the beginning of the operation.

When the resection is completed, the resectoscope is pulled just distal to the verumontanum, to see that there is no falling or obstructing tissue. Any remaining adenoma tissue can be judiciously trimmed down to the surgical capsule, taking care not to damage the sphincter mechanism.

Hemostasis is of prime importance, and must be maintained meticulously throughout the operation. The arterial bleeders are best coagulated at the level of the surgical capsule using spray coagulation. Complete hemostasis must be achieved at each stage, before resection proceeds to the other quadrant.

"Hemi-resection" of the prostate

TURP for large glands may be associated with significant morbidity, mainly due to absorption of irrigant and blood loss. When extensive resection of the prostate tissue is carried out, opening of venous sinuses can be associated with troublesome bleeding and/or excessive absorption of fluid, resulting in "TUR syndrome."

Similarly, in medically compromised elderly individuals (cardiomyopathy, ischemic heart disease, chronic obstructive respiratory disease, renal insufficiency, etc.) standard TURP may carry greater risk. In such patients the procedure may sometimes require to be terminated prematurely due to blood loss and/or excessive fluid absorption, because of the prolonged operating time.

However, incomplete resection leads to a large raw surface. Good hemostasis is not achieved because of the retraction of the blood vessels within the adenoma, leading to a greater incidence of hemorrhage and infection. In addition, incomplete resection of the prostate leads to poor flow rates postoperatively, and recurrent retention due to the "falling in" of the residual adenoma. It is also associated with a higher complication rate of reactionary and secondary hemorrhage, persistent postoperative urinary infection, and early recurrence [22].

In such a situation, an alternative solution is termination of the procedure after "complete" resection of one lateral lobe (and the median lobe, if present) of the prostate. This procedure, termed "hemi-resection" of the prostate (Figure 132.5), allows completion of the procedure quickly to avoid complications of excessive blood

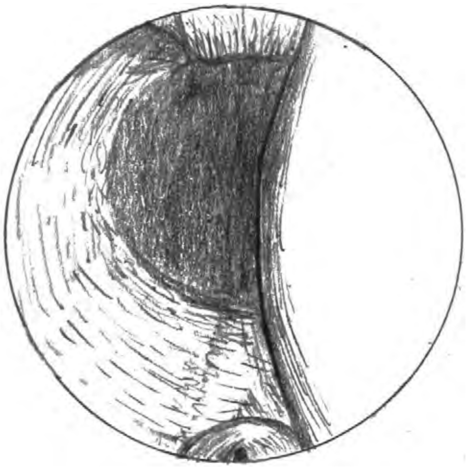

Figure 132.5 "Hemi-resection": endoscopic view.

loss and/or fluid absorption, while at the same time avoids the problems associated with "incomplete" resection.

The patients undergoing hemi-resection have the advantage of shorter operating time and less blood loss compared to those undergoing standard TURP. At the same time, complete resection of one lateral lobe (and the median lobe if present) prevents the complications of hemorrhage and persistent infection associated with incomplete resection, and ensures a good channel for adequate flow. The other lateral lobe that is left untouched remains attached to the surgical capsule of prostate and therefore does not "fall in" to obstruct the channel and increase the incidence of postoperative retention of urine. In addition, there is no raw area of incomplete resection as the mucosa over the unresected lobe remains intact.

In a propective randomized trial at our center in a series of 163 patients, the results of standard TURP and prostatic hemi-resection were found to be comparable in terms of reduction of PVR, improvement in symptom score, and peak flow rate [23]. No patient developed retention of urine in the postoperative period. The incidence of blood loss and TUR syndrome were lower in the hemi-resection group.

Prostatic "'hemi-resection" allows early termination of TURP in case of need, to avoid complications of excessive blood loss and fluid absorption. At the same time, it avoids the problems associated with "incomplete" resection. "'Hemi-resection" or "hemi-TUR" may be considered an acceptable option if the surgeon gets into trouble in the middle of an operation, or even as an elective operation in men with large glands and severe medical comorbidity, without compromising the basic principles of TUR surgery.

Postoperative care

Most urologists prefer to apply traction on the irrigation catheter for a period of 2–6 h. Continuous irrigation is provided with prewarmed fluids, with care taken to ensure proper outflow. The early postoperative period requires careful monitoring for prompt recognition of any complications. It is desirable to have an assessment of hemoglobin and electrolytes in this period. Patients are made to ambulate after traction is removed. Antimicrobials are continued until the patient is catheter free (i.e. 3–5 days).

Outcomes

The AHCPR panel (McConnell *et al.*) conducted a meta-analysis of various clinical studies and found the results of TURP to be significantly better in comparison to other less invasive procedures [24]. TURP improved symptoms in 70–96% of patients (mean 85%).

The mortality rates following TURP have shown a significant decline since the introduction of the procedure. The current mortality rates range from 0% to 0.25% [25]. This reduction indicates that progress has been made in making the procedure safer than it originally was. Technologic advances, such as microprocessor-controlled units, better armamentarium such as video TURP, and better training have contributed to this improvement.

Complications

Early complications

Hemorrhage

Hemorrhage is the most frequent complication. Larger glands and resection times of longer than 90 min are associated with a higher incidence of bleeding. The bleed can be arterial or venous and complicates both intraoperative and postoperative management. Arterial bleeding should be suspected if the irrigation catheter shows continuous passage of bright red blood. As a general principle, during resection all bleeding from an area of the prostatic fossa should be controlled using coagulation before moving to another area. Venous bleeding is darker and generally occurs after a period of initial clear irrigant in the postoperative period. Reapplication of traction on the catheter with or without over-inflation of the balloon can be useful in these cases. Excessive bleeding, especially if suspected to be arterial, may require repeat cystoscopy with electrosurgical coagulation to control the bleeding.

Resection errors

Over-resection with perforation of the prostatic capsule leads to extravasation of irrigant. It is characterized by restlessness, vomiting, and abdominal pain localized to the lower abdomen and back (a noticeable feature in a patient who has undergone spinal anesthesia). Immediate termination of the procedure with control of bleeding is of paramount importance in these patients. Most patients respond well to a period of catheter drainage and antibiotics.

TUR syndrome

This complex syndrome of fluid overload, dilutional hyponatremia, and hemolysis occurs due to systemic absorption of large amounts of irrigant, especially in patients with a gland size larger than 45 g and a resection time of more than 90 min. Mebust *et al*. observed that TUR syndrome occurred in 2% of patients [10]. The syndrome may occur as quickly as 15 min after the resection starts or up to 24 h postoperatively [26–29]. It is characterized by confusion, nausea, vomiting, hypertension, bradycardia, and visual disturbances. Monitoring the serum sodium concentration is important as the syndrome does not occur until the serum sodium falls below 125 mEq/dL. Intravenous hypertonic saline, diuretics, and termination of the procedure may be required when this happens. Madsen and Naber observed that limiting the height of the irrigation bottle to 60 cm above the prostate reduced the intravascular fluid absorption [30]. Leaving a rim of tissue on the capsule until the end of the procedure, where it can be left if signs of TUR syndrome are evident, may reduce the risk of absorption due to opening of prostatic sinuses [31, 32].

Obturator nerve stimulation

Most instances of obturator nerve stimulation occur following transurethral resection of bladder tumors and TURP is very infrequently implicated. When it occurs, stimulation of the obturator nerve produces a sudden thigh movement that can cause the cutting loop to bite more deeply and often at undesired locations. Various modalities have been tried to prevent adductor spasm during spinal anesthesia, ranging from local blockade of the obturator nerve, periprostatic and subvesical lignocaine infiltration, changing the site of the inactive electrode, reduction of the electrocoagulation voltage, and general anesthesia with muscle relaxants. However, local blockade of the obturator nerve seems to be the most effective in preventing this complication [33–35].

Intraoperative priapism

Intraoperative penile erection may be managed by injecting small boluses of an alpha-adrenergic agent (dilute ephedrine or phenylephrine) into the corpora cavernosa.

Sepsis

Pre-existing urinary tract infection should always be rectified and managed before undertaking TURP. Patients with long-standing indwelling catheters are at greater risk. Once infection is recognized, broad-spectrum empirical antibiotic therapy is started. Perioperative antibiotic prophylaxis has been shown to reduce the risk of events related to postoperative infection.

Late complications

Bladder neck contracture

This complication occurs 4–6 weeks after surgery and should be suspected in a patient complaining of poor stream who initially had a good flow postoperatively. Zwergel *et al*. reported bladder neck contracture in up to 2.7% patients following TURP [36]. It can be treated by bladder neck incision with a Collings knife.

Urethral stricture

Urethral strictures following TURP have been reported in 1.7% patients and can occur at the fossa navicularis (most commonly), bulbar urethra or prostato–membranous junction [36]. Strictures can be treated with sequential urethral dilatation and optical internal urethrotomy. The incidence of post-TURP stricture has declined significantly owing to the availability of better electrosurgical equipment and smaller sized resectoscopes, limiting the resection time, and use of lubricant jelly.

Incontinence

Thermal injury to the sphincter is the underlying mechanism in most patients who develop this complication of TURP. Detrusor instability and residual adenoma blocking the external sphincter mechanism may also contribute to this complaint. Transient incontinence is relatively common following the procedure, and most patients show spontaneous improvement in a few weeks or months. Kegel exercises and anticholinergics are useful in these patients. For refractory cases, collagen injections and artificial sphincters are needed.

Impotence

A small number of patients report impotence following the procedure, which may be psychogenic or due to age and prolonged abstinence following the operation. This complication needs to be studied well to eliminate the discrepancy in the reported literature (incidence 4–40%). In fully potent men, the risk of impotence after transurethral prostatectomy is fairly low, but it is higher in men who already have a degree of erectile failure. This risk has also been reported to be related to the incidence of capsular perforation at the time of surgery [37].

Tscholl *et al*. used the Snap Gauge tests to assess the incidence of erectile impotence in patients with intact potency preoperatively. Of the 98 patients studied, they observed that erectile dysfunction persisted in eight (8.3%) patients 3 months after the procedure [38]. Importantly, in their study 26 patients who had potency-related problems postoperatively improved in the subsequent 3 months.

Comparison with bipolar transurethral resection of the prostate

Monopolar TURP does suffer from a few inherent limitations. First, the patient is a part of the electrosurgical circuit, which can cause deep heating and the possibility of nerve damage. Second, the use of a hypo-osmolar irrigant implies that electrolyte imbalance and TUR syndrome will always remain bothersome concerns.

In recent years, bipolar TURP has emerged as an alternative to the standard monopolar TURP. Advocates of bipolar TURP cite comparable clinical efficacy with a better safety profile, especially in terms of lower instances of TUR syndrome and better hemostatic capability, as the primary reason for its superiority. Besides, some studies also indicate that duration of catheterization and hospital stay are shorter with this approach. These data seem promising, but large randomized trials with long-term follow-up are needed to further clarify issues related to long-term complications and cost, before bipolar TURP becomes universally accepted for managing BPH.

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CHAPTER 133

Bipolar Resection

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Introduction

Bipolar transurethral resection of the prostate (BiTURP) is an endoscopic technique used in the surgical management of lower urinary tract symptoms (LUTS) secondary to benign prostatic hyperplasia (BPH). It is a design modification of the monopolar transurethral resection of the prostate (TURP), utilizing a specialized resectoscope and loop that incorporates the active electrode on the loop and return electrode on a separate insulated part of the loop or on the inner sheath of the resectoscope. This allows the procedure to be performed using normal saline as an irrigant, thereby limiting the risk of dilutional hyponatremia (or transurethral resection syndrome), and with potentially less stray current because of the very short distance between the active and return electrodes. The electrode can be used to resect as well as to coagulate. Modifications of the electrode also allow vaporization, which will be discussed in a subsequent section.

Monopolar TURP, as described in Chapter 132, is a transurethral endoscopic procedure that relies on electrosurgical resection of prostate adenoma, followed by removal of "prostate chips" from the bladder with an aqueous evacuator. It has been performed since early in the last century, has evolved to be the procedure of choice for surgical treatment of LUTS secondary to BPH, and is often called the "gold standard" surgical treatment for BPH/LUTS. While monopolar TURP is known to be efficacious for the treatment of LUTS secondary to BPH, it is associated with reasonably high rates of complications, including hematuria, reoperation, dilutional hyponatremia, and the need for blood transfusion [1]. Advances in optics and energy generation/delivery systems have decreased complications significantly in modern times [2]. However, the number of TURPs performed in the USA continues to decrease yearly, perhaps because of the perception of increased morbidity [3].

The rationale for bipolar TURP (BiTURP), therefore, is straightforward: to limit the risk of dilutional hyponatremia while leveraging transurethral resection skills that most urologist acquire during training and practice. Most authorities suggest limiting monopolar TURP times to 60 min, because of the increasing risk of dilutional hyponatremia with increasing resection time under glycine irrigation [4]. The fact that BiTURP uses normal saline as an irrigant effectively eliminates this risk and allows operators to use this technique for as long as needed. This is particularly advantageous in patients with large volume prostates or in medical education.

It should be noted that this technique is actually an evolution of transurethral vaporization of the prostate [5], a monopolar technique that uses higher current and electrodes with broader contact with tissue to "vaporize" tissue at the cut edge of the resection. BiTURP has been referred to as bipolar vaporization of the prostate, plasmakinetic vaporization of the prostate or bipolar resection of the prostate. This nomenclature adds to confusion, particularly with strictly ablative techniques such as KTP laser vaporization of the prostate or bipolar button vaporization electrode. The "vaporization" referred to in BiTURP is actually the vaporization that occurs of tissue in contact with the cutting loop (active

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electrode). This is similar to what happens to tissue in contact with the cutting electrode during monopolar TURP. BiTURP relies on the creation of a "plasma corona" at the electrode and this results in roughly 20% of the tissue being vaporized, with the rest resected as prostate chips [6].

BiTURP was first introduced in humans in the early part of this century [7]. The initial reports touted this technique's ability to use bipolar current through an isotonic irrigant media with results similar to TURP. Most subsequent reports have focused on technologies from different manufacturers and primarily compared results to TURP in either randomized controlled trials or comparative trials.

Patient selection

Surgical therapy is the mainstay for treatment of LUTS secondary to BPH and refractory to medical therapy. Current practice is to offer minimally invasive surgery to patients who do not want or are unfit for a more involved operation . Endoscopic surgery is the gold standard for treatment of LUTS secondary to BPH, with open surgery reserved for those patients with large glands or those who need concomitant procedures [8].

The most recent American Urological Association (AUA) guidelines [8] on the management of BPH/LUTS recommend TURP as the surgical treatment of choice for men with moderate-to-severe LUTS who are bothered by their symptoms. Because these guidelines were published near the advent of BiTURP, they state that saline bipolar technologies be considered experimental. The revised version of the AUA guidelines is expected shortly and will likely recommend BiTURP as an option for surgical treatment of moderate-to-severe BPH/LUTS.

Surgical equipment

BiTURP is an endoscopic resection technique that uses a continuous flow resectoscope and a specially designed loop and inner sheath that varies by manufacturer and use. As opposed to monopolar TURP, the irrigant media is usually 0.9% normal saline. Generators are also matched to the loop used and adjust voltage based on impedance to keep current constant.

Technology

Bipolar technology platforms currently available are the PK system by Gyrus/ACMI, an Olympus Corporation (Tokyo, Japan) company, the TURis system by Olympus Corporation, and a bipolar resection system by Karl Storz (Tuttlingen, Germany). Each of these systems uses a continuous flow resectoscope and relies on an active electrode on the cutting element of the loop, with the ability to generate a plasma corona vaporization field in normal saline. The difference between these platforms is the location of the return electrode. Because BiTURP relies on the ability to generate a current between two poles and the closer the two poles, the lower the voltage needed to generate a current, the return pole (electrode) has to be in close proximity to the active electrode. As such, the return electrode of the PK system is on the loop itself, separated from the cutting element by a few millimeters of insulation (Figure 133.1). The return electrode TURis system is on the inner sheath of the resectosope (Figure 133.2), and the return electrode for the Storz system is on the loop opposite the cutting element.

Image not available in the electronic edition

Figure 133.1 The Gyrus PK Supersect loop (reproduced by permission of Gyrus ACMI).

BiTURP, which typically needs a lower voltage differential to generate a high current because of the short distance needed to close the circuit, relies on generators that can change voltage based on tissue impedance and therefore keep current constant. Specially designed generators are matched to each platform. All generators have preset default settings; typical settings for "cutting" are high power (200–280 W for TURis, 160–200 W for PK) and settings for "coagulation" are lower power (120 W for TURis and 80 W for PK). Different loops are also available for the PK system and the TURis system to allow resection of bladder tumors or to perform vaporization without resection. All currently available loop electrodes are single use. Figure 133.3 is an illustration of the Gyrus PK generator.

Surgical technique

The surgical technique for BiTURP is similar to monopolar TURP, with a few unique aspects. As in other transurethral procedures, preoperative antibiotics should be given. Regional anesthesia (e.g. spinal) or general anesthesia may be used. It is important to note that there should be no dilutional hyponatremia with BiTURP, eliminating the need to monitor mental status and allowing general anesthesia to be used at the anesthesiologist's discretion.

Image not available in the electronic edition

Figure 133.2 Olympus TURis bipolar loop. HF, high frequency (reproduced by permission of Gyrus ACMI).

Image not available in the electronic edition

Figure 133.3 Gyrus PK generator (reproduced by permission of Gyrus ACMI).

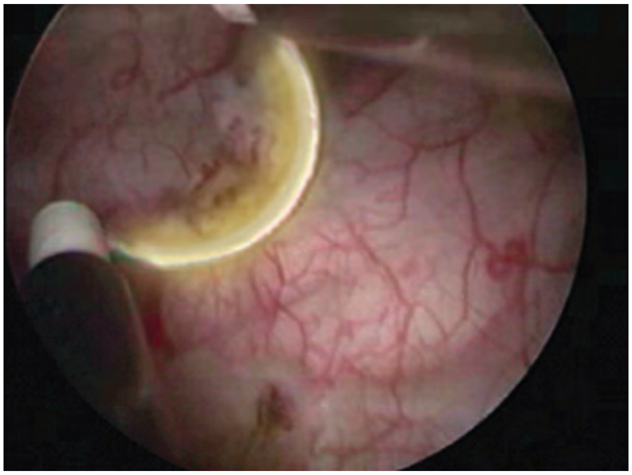

Figure 133.4 Plasma corona firing in the bladder.

Initial intubation of the urethra should be performed with the help of a visual obturator. If needed a urethrotomy may be performed to allow entry of larger resectoscopes. Once the bladder is reasonably filled, continuous irrigation should be started, typically with the outflow port open to gravity drainage. Resection begins with resection of the intravesical component and the median lobe of the prostate. Unlike the monopolar TURP, the cutting electrode loop needs to develop a "plasma corona" prior to the start of resection (Figure 133.4). The loop should not be in contact with prostate tissue when the operator initiates the cutting current via the foot pedal. At the beginning of the case, this is typically done with the electrode in the bladder and slightly off the prostate surface. Once the corona is formed, resection proceeds in an antegrade fashion for the length of the loop excursion. Prostate chips are formed similar to those in monopolar TURP and are forced into the bladder by the inflow of normal saline irrigant.

The resection should be performed systematically as in a conventional TURP with prostate landmarks used to limit resection, in particular the verumontanum at the apex. Typically, the intravesical component is first resected, followed by the median lobe from the bladder neck to the verumontanum. Care should be taken to avoid injury to the ureteral orifices during this step. Next, one of the two lateral lobes is resected in its entirety prior to proceeding to the other one. Finally, apical tissue and anterior tissue are resected. During resection, the plasma should always be visible. This is especially important as the procedure proceeds, because charred tissue accumulating on the surface of the cutting loop, will add impedance to the circuit. As stated above, the corona should be initiated within the bladder or in the lumen of the prostatic urethra without contacting prostate tissue. If the time between stepping on the cutting pedal and the formation of the plasma corona starts to become long, the operator should place the loop in the center of the bladder and allow the plasma to fire for a few seconds. This will clean the loop electrode and allow more efficient vaporization.

Once the surgical endpoint is reached, specifically the entire adenoma has been resected from bladder neck to verumontanum and capsular fibers are visible, hemostasis should be achieved. This is done with the coagulation current. During coagulation, no plasma is formed. Instead of point coagulation, as in monopolar TURP, BiTURP relies on coagulating a surface around the bleeding vessel. This is likely due to the shallow penetration of current during BiTURP. Of note, coagulation should be performed intermittently throughout the procedure if significant bleeding is encountered as this will improve visibility during the case.

Prostate chips, which should have been deposited in the bladder, are removed with help of an aqueous evacuator. Once all chips have been removed and this has been confirmed by a final survey of the base of the bladder and prostate fossa, a three-way urethral catheter is inserted and continuous bladder irrigation is begun. Typically, this irrigation is titrated off by the first postoperative day, and the catheter removed. Patients are discharged with a few days of antibiotics. The prostate chips are evaluated by surgical pathologists in a manner similar to that for prostate chips removed during a monopolar TURP, and the same conventions are used to report findings, including T1a or T1b prostate cancer in cases of previously unsuspected prostate cancer. If T1a or T1b prostate cancer is found and the patient is a candidate for prostate cancer treatment, a transrectal ultrasound (TRUS)-guided biopsy of the prostate should be performed once the patient has healed from the BiTURP, typically 6 weeks to 3 months after the procedure.

Post-discharge management is similar to that with monopolar TURP and is dependent on the surgeon. Typically, patients can expect mild hematuria which resolves within days and can also expect a temporary increase in frequency and urgency of urination. There may be a period of recurrent hematuria 2–4 weeks after the procedure, managed by increasing oral hydration. Follow-up visits are usually at the 3-, 6-, and 12-month time points. At each follow-up visit, the International Prostate Symptom Score (IPSS) is collected along with uroflowmetry data and measurement of postvoid residual urine (PVR). A serum prostate-specific antigen (PSA) should be obtained at the 12-month visit if indicated. Of note, if patients were candidates for prostate cancer screening at the time of BiTURP, a preoperative serum PSA and digital rectal examination should have been performed, and if either one was abnormal, a TRUS-guided biopsy of the prostate should also have been performed.

Efficacy

The first reports of BiTURP in humans came in the early part of this century. Botto *et al*. published a pilot study in 2001 of 42 patients who underwent electrovaporization of the prostate using saline bipolar electrocautery with the Gyrus system [7]. These investigators reported 3-month results following treatment of men with symptomatic BPH without suspected prostate cancer. They noted that no men had significant postoperative bleeding and the mean catheterization time was 1.4 days. Two of the 42 patients developed urethral strictures requiring treatment. Mean length of stay was 2.2 days. At 3 months, IPSS decreased from 16 at baseline to 9 and peak flow rate (Qmax) on uroflowmetry increased from 7.9 mL/s to 19.7 mL/s. Based on these short-term results, the authors concluded that the Gyrus system for electrovaporization of the prostate is useful and safe.

Yang *et al*. subsequently performed a randomized prospective study comparing the Gyrus BiTURP to conventional monopolar TURP [9]. They enrolled 117 patients, 58 in the BiTURP group and 59 in the monopolar TURP group, and followed these patients for 3 months. The authors noted that both groups reported significant improvements in IPSS (BiTURP, 20.9 preoperatively to 10.8 at 3 months; TURP, 21.6 preoperatively to 11.1 at 3 months) and Qmax (BiTURP, 10.4 mL/s to 17.1 mL/s; TURP, 10.9 mL/s to 14.8 mL/s), but no statistically significant difference between groups. In their study, complications occurred at the same rate in both groups; notably only one patient developed TUR syndrome in the monopolar TURP group and none in the BiTURP group. These authors concluded that monopolar TURP and BiTURP yielded similar results but longer follow-up was necessary to establish long-term efficacy.

At roughly the same time, Fagerstrom *et al*. performed a randomized trial comparing operative performance of the Olympus TURis BiTURP to conventional monopolar TURP [10]. These investigators randomized 202 patients, 185 of whom were evaluable. They noted that both groups had similar tissue resection weight, but that blood loss and hemoglobin decrease were more in the TURP group than the BiTURP group. These authors concluded that BiTURP causes less bleeding that the monopolar TURP technique.

Starkman and Santucci retrospectively compared their results for 18 consecutive patients who underwent monopolar TURP with a subsequent consecutive group of 25 patients who underwent Gyrus PK BiTURP [11]. These authors reported results after an observation period of approximately 1.5 years to evaluate long-term complications. Weights of resected tissue were similar in both groups and they noted shorter catheterization times (3.2 days for monopolar TURP vs 1.8 days for BiTURP) and shorter length of stay with BiTURP (2.1

days for monopolar TURP vs 1.2 days for BiTURP). Acute complications included two of 18 monopolar TURP patients with dilutional hyponatremia and interestingly, one of 25 BiTURP patients with dilutional hyponatremia. Other acute complications were minor, but higher in the monopolar TURP group as compared to the BiTURP group (33% vs 16%). Long-term complications consisted of one bulbar urethral stricture in each group, a patient who developed a bladder neck contracture related to radiotherapy for a subsequent prostate cancer diagnosis in the BiTURP group, and a patient with persistent stress urinary incontinence in the monopolar TURP group. Long-term complications were not statistically different between the groups.

De Sio *et al*. randomized 70 patients to treatment with Gyrus PK BiTURP or monopolar TURP and reported 12-month results [12]. Like the groups before, they found a decreased mean catheter time (100 h for monopolar TURP v 72 h for BiTURP) and mean length of stay (107 h for monopolar TURP vs 78 h for BiTURP) in the BiTURP group. No difference was found between the groups in 12-month IPSS, Qmax, or PVR: IPSS decreased from 20 preoperatively to 4 at 12-month follow-up in both groups; Qmax improved from roughly 5 mL/s preoperatively to 20 mL/s at 12-month follow-up in both groups; and PVR decreased from roughly 80 mL preoperatively to roughly 20 mL at 12-month follow-up in both groups. These authors noted no significant difference in adverse events.

Seckiner *et al*. similarly performed a randomized study comparing Gyrus PK BiTURP to monopolar TURP [13]. These authors compared 24 patients in each group and followed them for 12 months. There was no significant difference in operative and perioperative data, except for decreased serum sodium in the monopolar TURP group, with two patients in this group exhibiting mild dilutional hyponatremia. Like previous authors, these authors reported significant improvements in IPSS, Qmax, and PVR in both groups compared to baseline values but did not show any difference between groups.

Ho *et al.* performed a randomized study comparing Olympus TURis BiTURP (48 patients) to standard monopolar TURP (52 patients) and followed these patients for 12 months [14]. No differences in resection time or resection weight were noted. These authors did note significant decrease in serum sodium in the monopolar TURP group compared to the BiTURP group, with two cases of clinically significant dilutional hyponatremia in the former but none in the latter. Urethral strictures were observed in three of 48 patients in the BiTURP group and one of 52 patients in the TURP group. These authors also showed significant improvements in IPSS and Qmax at 12 months from baseline in both groups but no differences between groups. These authors concluded that monopolar TURP and BiTURP were equally efficacious, with BiTURP having a better safety profile.

Iori *et al*. performed a clinical and urodynamic evaluation of 51 patients with urodynamically proven bladder outlet obstruction and randomized to monopolar TURP (26 patients) or to BiTURP (27 patients) [15]. Mean follow-up was 12 months. There was no difference in resection time, catheterization time, or length of stay between the groups, or in change in serum hemoglobin or serum sodium. Of note, all patients underwent urodynamic evaluation prior to the procedure and at 12 months postoperatively. The Schaefer obstruction class was significantly improved after both procedures and as with other parameters, there was no difference in the urodynamic effects after monopolar TURP and BiTURP.

Michielsen *et al*. performed a large randomized trial comparing conventional monopolar TURP (120 patients) to Olympus TURis BiTURP (118 patients) [16]. These authors focused on intraoperative parameters and immediate perioperative morbidity. They noted no difference is resected prostate tissue weight and duration of hospitalization between groups. They did note that BiTURP took longer to perform, but that decrease in serum sodium was significantly greater for the monopolar TURP group. There was one case of TUR syndrome in the monopolar TURP group and none in the BiTURP cohort.

BiTURP has been reported to be a safe alternative to monopolar TURP for use in resident teaching and for the management of large-volume prostates. Bhansali *et al*. performed a randomized trial of 70 patients with prostate sizes greater than 60 g, comparing Gyrus PK BiTURP to monopolar TURP [17]. They noted no differences in length of stay or function outcomes at 9 and 12 months postoperatively between the two cohorts. They did notice significantly more blood loss, significantly longer catheterization time, and significantly larger changes in serum sodium in the monopolar TURP group compared to the BiTURP group. The authors concluded that it is safe to perform BiTURP in large-volume prostates.

Gilleran *et al*. commented on using BiTURP in an academic setting to help teach residents how to perform an adequate TURP [18]. These authors reported results of a series of 21 men who underwent Gyrus PK TURP in an academic setting. They noted that despite small size prostates (median resected tissue weight 20 g), the median resection time was 65 min, which is much longer than would be expected for the amount of tissue resected. While they did note a significant decrease in serum hemoglobin between preoperative and postoperative values, they did not report a significant difference in serum sodium and no patients needed blood transfusions. The authors concluded that BiTURP is a safe modality for resident medical education.

Large series of BiTURP have been reported recently. Martis *et al*. reported their series of 401 patients who underwent Gyrus PK BiTURP and noted no intraoperative complications [19]. They reported excellent and durable functional results measured by IPSS and Qmax through 36 months of follow-up. Three patients developed urethral strictures that were effectively managed with internal urethrotomy. Puppo *et al*. reported outcomes and complications after the first 1000 cases of Olympus TURis system resection, including 376 BiTURPs [20]. Other procedures using the saline bipolar technology in this report were 480 bladder tumor resections and 144 transurethral incisions of the prostate. The authors noted no cases of TUR syndrome and operative and function results better than in comparable series of monopolar TURP.

Mamoulokis *et al*. recently reported a systematic review and meta-analysis of all randomized control trial of BiTURP [21]. A total of 16 randomized controlled trial with 1406 patients which were included in the meta-analysis. The authors noted that efficacy of BiTURP was comparable to monopolar TURP, with respect to IPSS and quality-of-life metrics. However, Qmax was significantly improved with BiTURP over monopolar TURP at 12 months. This was weighted by one trial which showed marked improvements for BiTURP over monopolar TURP. The meta-analysis also evaluated decreases in serum sodium and incidences of TUR syndrome. There was a significantly larger difference in serum sodium decrease in patients undergoing monopolar TURP compared to BiTURP. Of note, while none of the individual studies showed a difference in the incidence of TUR syndrome, the pooled analysis did detect a significantly higher rate of TUR syndrome in patients who underwent a monopolar TURP compared to a BiTURP. The number needed to treat to prevent one case of TUR syndrome was 50.

Morbidity/complications

BiTURP appears to be safer than monopolar TURP, especially with regards to decreases in serum sodium and incidence of dilutional hyponatremia. All studies that report on serum sodium show a decrease and the meta-analysis performed by Mamoulokis *et al*. confirmed that serum sodium decreases and incidence of TUR syndrome are both significantly higher in monopolar TURP arms as compared to BiTURP arms [21]. BiTURP has not been compared to other prostate ablation modalities such as laser prostatectomy that also use normal saline as an irrigant.

Urethral strictures were noted to be higher in the early BiTURP studies, particularly in the study by Tefekli *et al*. that evaluated a hybrid vaporization/resection technique using Gyrus equipment [22]. These authors compared their saline bipolar technique to monopolar TURP and noted similar efficacy but a significantly higher rate of urethral strictures in the bipolar cohort. Other authors have suggested that the large cystoscope needed to perform continuous flow BiTURP and possibly longer operative times may be associated with an increased incidence of urethral strictures [16]. A unique aspect of Olympus TURis BiTURP has also been implicated; the fact that current returns through the inner sheath [14]. An equipment malfunction could potentially expose the urethra to active current, potentially leading to urethral strictures. Despite the fact that the cutting loops for TURis are single use, some authors have speculated that reusing the loops leads to a higher stricture rate. The pooled analysis of all BiTURP randomized control trials has not shown a higher rate of urethral stricture and in fact shows comparable stricture and bladder neck contracture rates with BiTURP and monopolar TURP [21].

The perception of increased intraoperative and postoperative blood loss with BiTURP remains controversial. While early reports of coagulation zone after saline bipolar resection showed a smaller zone of coagulation than monopolar TURP [23], more recent report have shown a larger zone [24] and others have shown differences in size of zone measured immediately postoperatively and that measured a few days postoperatively [25]. It remains unclear whether decreased or increased zone of coagulation is beneficial as far as hematuria. Regardless, the pooled meta-analysis showed no difference in intraoperative or postoperative blood loss following BiTURP compared to monopolar TURP [21].

Cost

The cost of BiTURP is an important consideration, especially with pressures on most healthcare systems to control cost of healthcare. The Urologic Diseases in America project estimated that over US$1 billion was spent in the USA on the management of BPH, not including costs of medicines [3]. It appears that BiTURP may be less expensive than monopolar TURP despite increased capital costs and increased disposable costs. This has been postulated to be because of potential decreased length of stay and possibly decreased postoperative complications with BiTURP. BiTURP has not been compared to other modalities for prostate debulking, but is likely to be at least competitive with these. The fact that BiTURP is a technique that most urologists have learned in graduate medical education may decrease the training costs associated with learning newer techniques such as laser prostatectomy. However, these new modalities may offer similar improvements in length of stay and morbidity as compared to BiTURP, just as BiTURP has done compared to monopolar TURP.

Whether the differential in these recurring costs is greater than initial capital outlay remains to be seen.

Education issues

BiTURP has been touted as a useful adjunct for urology graduate medical education [6, 18], due to the decreased risk of dilutional hyponatremia and therefore more time available for resident operative teaching. While this is valid, it should be noted that the number of TURPs, monopolar or bipolar, has been declining for decades [3]. In fact, over a 7-year period during which BiTURP was available, graduating chief residents performed approximately 25% fewer cases [26]. This might be due to an increase in other ablative treatments such as laser prostatectomy and may be a reversible trend if BiTURP is adopted by the urologic community.

A more fundamental question is the role of TURP in the management of BPH/LUTS. With the advent of effective medical therapy and availability of a host of other ablative and minimally invasive techniques for the surgical management of BPH/LUTS, the TURP procedure may be performed less and less often and therefore may not remain the "gold standard." If this were to happen, some of the advantages of BiTURP may be less obvious.

Conclusions

BiTURP is an effective modality for the surgical management of BPH/LUTS. It has been in use for only about a decade and during that time it has demonstrated efficacy similar to monopolar TURP with a potentially improved safety profile. It has not been compared to other transurethral ablative therapies for the prostate that use saline as an irrigant. If TURP remains the "gold standard" for surgical management of BPH/LUTS in the future, then BiTURP will continue to have an increasing role.

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CHAPTER 134

Bipolar Vaporization of the Prostate

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Introduction

Transurethral resection of the prostate (TURP) has long been accepted as the gold standard surgical treatment of benign prostatic hyperplasia (BPH). It is the measuring stick for all other minimally invasive treatments for BPH as traditional TURP is highly effective in improving urinary flow rates and decreasing symptom scores; the Agency for Health Care Policy and Research (AHCPR) panel guideline meta-analysis showed that patients had an 88% chance of symptomatic improvement after TURP [1]. However, due to the morbidity associated with monopolar TURP, including the risk of bleeding, clot retention, impotence, urethral stricture, and transurethral resection (TUR) syndrome, as well as the length of hospitalization and catheterization, urologists have been tinkering with other minimally invasive treatments for BPH for decades.

Vaporization of the prostate was first described in the early 1990s using either conventional electrical surgery, termed electrovaporization, or laser techniques [2]. Subsequently, transurethral vaporization of the prostate (TUVP) was first described by Kaplan *et al.* in 1995 [3]. The proposed advantages of TUVP included less blood loss, shorter catheterization time, and shorter hospitalization, all the while maintaining efficacy. Initially, electrovaporization techniques were performed using monopolar currents. Monopolar current has its own associated problems. First, the use of a conductive irrigant is required, such as glycine or mannitol, which may result in systemic absorption of hypotonic fluids, thus risking hyponatremia and TUR syndrome. Second, the patient is part of an electrical circuit that can pose a risk for patients with pacemakers and cause diathermy burns at the site of the return plate. Third, monopolar current does not allow simultaneous cutting and coagulation. Therefore, bipolar electrocircuitry was developed for minimally invasive prostate surgery to address some of the aforementioned issues. Bipolar vaporization or resection allows normal saline to be used, which is isotonic, avoids the need for a return plate as the patient is not part of the electrical circuit, and allows simultaneous cutting and coagulation.

Bipolar electrovaporization of the prostate was first described in 2001 using a Gyrus device [4]. Since then, numerous centers have reported level 1 evidence for favorable short-term outcomes using bipolar vaporization of the prostate. Herein we present a review of the mechanism of action of bipolar vaporization, various electrode and generator designs, clinical experience, and relevant comparative studies.

Mechanism of action

Vaporization is produced via the application of energy to the prostate, which results in heating of the tissues. The tissues are primarily composed of intracellular water, which subsequently boils at a rapid rate, thus producing steam. This results in cellular disruption and tissue destruction, thus leaving a void where the cells were previously present. In electrosurgery, the rate of electrical energy delivered is measured in watts (W), current (I) flows through the tissue, and the tissue creates electrical impedance (R). Heat is created due to

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the electrical impedance of the prostate to current flow, therefore:

$$W = I^2R$$

Most of the energy delivered to the prostate results in vaporization of the surface layer of cells; however, some of the energy has been shown to disperse below the vaporization layer to create a zone of coagulation, resulting in improved hemostasis. This phenomenon of simultaneous vaporization/ablation and coagulation is the principal benefit of TUVP techniques. The actual depth of coagulation depends on system and electrode design. The technique employed by the surgeon will also impact the depth of coagulation as this is increased by increased pressure on and time in contact with the tissue. Importantly, coagulation has to take place with bipolar technology at lower peak voltages compared to monopolar surgery [80–100 V for the PlasmaKinetic (PK) system] as higher voltages will convert the liquid into a gaseous phase, resulting in higher impedance. The impedance therefore is changed from a resistive to a capacitative mode, thus reducing energy flow, dissipating heat, and decreasing the final coagulation effect.

In bipolar and monopolar cutting, the generator must initiate a momentary high-energy spike to initiate a plasma vapor layer. This layer is ionized in the form of a nonequilibrium plasma, where plasma ions and electrons are responsible for current flow. In monopolar circuitry, the current arcs to the tissue and passes through the patient to a large surface return electrode on the skin heating the intervening tissue by ohmic resistance. However, in bipolar surgery, the active and return electrodes are in close proximity to each other, separated by an insulator. The electron emission from the smaller active electrode heats and vaporizes the adjacent intracellular water to form a thin gas layer (plasma pocket) that grows and forms a larger bubble containing energetic species that can dissociate both water and organic molecules, resulting in the net tissue effect [5]. It is likely that the thermal effect noted with bipolar surgery takes place at much lower temperatures (<70° C) compared to monopolar surgery (300–400° C). Once the plasma vapor pocket is formed, it can be maintained at low voltages (100–350 Vrms) as the electrode is close to making contact with the tissue. Tissue destruction ensues due to the breakdown of carbon–carbon and carbon–nitrogen bonds. This results in the production of elementary molecules and low molecular weight gases, including carbon dioxide, oxygen, nitrogen, and hydrogen. Intraoperatively, the effect is precise cutting and vaporization with minimal collateral damage as the charged sodium ions contained within the plasma vapor pocket have only a short estimated range of penetration (50–100 μm). This is largely due to electrosurgical principles as minimization of collateral tissue damage is dependent upon resistive heating caused by any current flowing through tissue and by limiting thermal transfer from the electrode sources. The final result in the human prostate is precision tissue cutting/vaporization with minimal charring and burnt prostate odor traditionally equated with monopolar TURP.

Specialized generators were developed along with the bipolar technology using radiofrequency (RF) energy output. The initial bipolar vaporization of the prostate used a Gyrus device and generator designed with a 200-W capability with an RF range of 320–450 kHz and a voltage range of 254–350 V [4]. However, the Vista Coblation system (ACMI Corporation, Southborough, MA, USA) used RF energy output from a specialized electrosurgical generator that is one-fifth that of monopolar generators (100-kHz square wave) [6]. The initial Olympus SurgMaster generated an RF output of 350 kHz and a recent report used the UES-40 SurgMaster (Olympus Winter & Ibe GmbH, Hamburg, Germany) with a power output of 290 W and 120 W for vaporization and coagulation, respectively (Figure 134.1) [7]. The frequency of the newest system from Karl Storz (Autocon® II 400 Electrosurgical System; Tuttlingen, Germany) (Figure 134.2) generates an RF output of 350 kHz with a power output of 120 W for coagulation.

Figure 134.1 UES-40 Electrosurgical Generator (reproduced by permission of Olympus).

STORZ
autocon II 400
205352 20
300
5
200
5

Figure 134.2 Karl Storz Autocon® II 400 Electrosurgical System (reproduced by permission of Karl Storz).

Electrode and generator design

The bipolar technology was developed with the active and return electrodes in close proximity to one another, separated by an insulator. Energy from the generator travels through the active electrode, through the plasma pocket, through the conductive solution to the tissue bed, and returns via a thicker electrode to the active cord to the ground. Hence, there is no need for any energy to travel through the patient to a return electrode on the skin, eliminating the risk for inadvertent burns from inadequate contact. Also, the low operating frequency and voltage of bipolar surgery should eliminate any potential for interference with cardiac pacemakers.

There are several challenges to electrode design, including establishment of a reliable plasma corona preferentially at the distal active electrode, to achieve a plasma condition with short delays from the time of foot-switch activation by the surgeon, to provide adequate hemostasis from both cut and coagulation sources of foot-switch operation, and to maintain this under all surgical conditions. With these challenges in mind, manufacturers and urologists are still in search of the "ideal" electrode for bipolar TUVP. The commercially available electrodes vary in size and configuration; however, in general, the active component is slightly thinner and separated by the thicker return electrode component by an insulator. The commercially available systems also vary in terms of resectoscope sizes, design of electrode housings, and coupling mechanism between active and return cords.

The PK® Gyrus system was the first bipolar vaporization technology reported in the literature and therefore had to address several of these early technical issues. For bipolar vaporization to occur, at the time of foot-pedal activation, the active electrode must be in close proximity to the tissue because if the gap is too wide or if there is insufficient power, current flow is dissipated by the large volume of electrolyte solution in a full bladder and there is no effect on the tissue. Furthermore, if the power/voltage spike is not great enough to maintain the plasma pocket, cutting and vaporization of the tissue will occur in a stuttering fashion, depending on the quality of tissue contact.

With these limitations and challenges in mind, the initial PK® Gyrus system was modified, resulting in a second-generation model called the PK® SuperPulse® Generator. There are several advantages of this system. First, this device is preconfigured for maximal allowable current under low impedance conditions. Second, the surgeon can choose between two sets of preset cutting voltages. Third, the generator is designed to recognize the active electrode offering default settings that are optimal for a wide range of conditions at the tip. Lastly, the PK SuperPulse generator is equipped with a row of internal capacitors acting as an energy reservoir to ensure sufficient voltage for instantaneous fire-up and for power ride-through under challenging conditions of impedance. These modifications have resolved the issue of stuttering cutting/vaporization that occurred previously. The capacitor reservoir can provide up to 4000 W of power for short periods of time (10 ms) if the tip impedance is low enough. This may be important because under conditions of high flow with cold saline, more power than normal is required to create and maintain the initial plasma pocket at the active electrode tip.

At baseline, prior to RF voltage application, the impedance differential between bipolar active and return electrodes is between 23 and 60 ohm with variability due to the irrigation temperature and the proximity of the active electrode to the tissue bed. The PK SuperPulse generator can generate a high enough power (4000 W) at low impedance (23 ohm) to sustain a voltage of close to 300 Vrms that boils the saline immediately surrounding the active loop in a matter of milliseconds. This phenomenon is largely due to the electrode design. The electrical current crowds at the reduced surface area of the active electrode, resulting in a nonequilibrium vapor pocket containing charged sodium ions. The activated sodium ions form the plasma inside the vapor pocket and produce the orange glow that is visible to the naked eye. There is a time delay of 1–2 µs from the initial negative current spike until light is emitted. Once the plasma is formed, the impedance increases greatly from 500 to 3000 ohm, depending on whether the electrode is in contact with the vapor pocket versus the irrigant, and or the length of the vapor pocket (as there is a higher impedance with longer plasma vapor pocket lengths). The power delivery now becomes focused around the active electrode and is not dissipated in the surrounding saline solution and prostate tissue, and therefore much less power is required to sustain the plasma vapor pocket. The energy reservoir can then be replenished as the output voltage falls by being repeatedly formed during each half cycle of the high-frequency exciting voltage waveform.

The PK SuperPulse generator has two sets of preset cutting voltages (termed SP1 and SP2). At the lower preset voltage of SP1, plasma volume is smaller and impedance is lower, and detected intraoperatively as a less intense orange glow around the active electrode. The SP2 setting can be used during suboptimal operative conditions when cutting/vaporization becomes difficult, to allow for an increased plasma volume and slightly higher preset voltage. Foot-pedal activation and fire-up should take no longer than 20 ms as a result of the energy reservoir of the internal capacitors. Once an activated electrode is in contact with tissue, *in vivo* studies have demonstrated that no more than 100 W are usually required to sustain the user-defined maximum voltages.

Clinical experience

Bipolar TUVP has been in clinical use for a decade. The initial experience was reported in 2001 by Botto *et al.* using the Gyrus device and a rolling-type electrode (Axipolair®) [4]. This pilot study utilized the first-generation PK Gyrus generator and the electrode consisted of an active component (manufactured from 80/20 platinum/iridium alloy) and a return electrode (manufactured from stainless steel) placed on the same axis. A ceramic insulator separated the active and return electrodes. The initial technique describes vaporizing the obstructing tissue by placing the electrode in direct contact with the prostate in a systematic fashion similar to the technique for traditional TURP. The two major differences in performing bipolar TUVP include modeling the prostatic cavity in a circumferential action and the need to activate the current prior to bringing the electrode into direct contact with the tissue to allow the vapor pocket to build up. Therefore, for experienced endoscopists, the learning curve for bipolar TUVP is quite minimal. Forty-two patients with symptomatic BPH were included in this study and underwent bipolar TUVP using a standard 27F resectoscope sheath and normal saline as irrigant. A majority of the patients (19) had a prostate volume between 30 and 60 mL and 93% of the operations took less than 60 min to complete. The mean postoperative hospitalization (including the day of surgery) was 2.2 days and all patients passed a voiding trial prior to discharge home. Early complications included bulbar urethral stricture in two patients requiring endoscopic urethrotomy, and dysuria in four patients, two of whom complained of dysuria for 3 months. Functional outcomes were assessed with International Prostate Symptom Score (IPSS) and maximum flow rate (Qmax) at baseline and at 3 months. Mean IPSS decreased from 19 to 9 and mean Qmax increased from 7.9 mL/s at baseline to 19.7 mL/s at 3 months. These early clinical results showed feasibility, safety, and acceptable short-term outcomes that warranted further study.

Eaton and Francis performed bipolar TUVP in 40 patients with BPH symptomatology in a day surgical unit setting in the UK [8]. Similarly, bipolar TUVP was carried out using the Gyrus PK tissue management system (Gyrus Medical Ltd, Buckinghamshire, UK), which involved a 27F continuous flow resectoscope sheath and normal saline irrigation. The mean operative time was 33 min (range 12–52 min) and mean prostate volume was 34.9 mL (range 15–76 mL). No patients had any electrolyte abnormalities or significant drop in hemoglobin level postoperatively. All but six patients were discharged home on the day of surgery, with an average hospital stay of 5.9 h. All patients voided successfully at 48 h, but two returned with obstructed catheters, thought to be due to coagulum and not blood clot or tissue fragments. At 4 months there was an improvement in IPSS and quality of life by 64% and 83%, respectively, and an improvement in mean flow rate of 200%, but no baseline data were reported in any of these categories.

Dincel *et al*. reported on their initial experience with bipolar TUVP using the Gyrus PK tissue management system and a Plasma-V™ electrode (Figure 134.3) [9]. Twenty-one men with moderate-to-severe lower urinary tract symptoms (LUTS) attributable to BPH underwent bipolar TUVP, of whom 20 returned for follow-up and were available for final analysis. The median prostate volume was 42 mL and the operative time increased as the size of the prostate increased (median 55 min). The median duration of catheterization and time to discharge was 3 days. The only perioperative complication reported was constipation in one patient who required readmission due to clot retention and was transfused two units of blood. Median IPSS and urine flow rates were significantly better at 90 days postoperatively, and postvoid residual urine volume (PVR) had significantly decreased from a median of 54 mL to 19.5 mL. Serum PSA values were measured preoperatively, postoperative day 1, 30 days postoperatively, and 90 days postoperatively. Serum prostate-specific antigen (PSA) values were significantly increased on postoperative day 1, and then trended back towards preoperative levels by 90 days postoperatively, prompting the authors to suggest that serum PSA levels should not be obtained in patients who have undergone bipolar TUVP until at least 30 days postoperatively. Furthermore, in these early studies, patients were heavily screened preoperatively for prostate cancer with serum PSA measurements and digital rectal examination (DRE), as it is important to note that no tissue is retrieved from TUVP for pathologic analysis. Therefore, patients with abnormal PSA/DRE were excluded from participation in these studies. While the results of these nonrandomized clinical trials were promising and sparked the interest of the urologic community, large randomized prospective trials with long-term follow-up were needed to provide better evidence-based medicine rationale for the use of this new technology.

Comparative studies

In 2003, Dunsmuir *et al.* reported the first randomized prospective clinical trial comparing bipolar TUVP to traditional monopolar TURP [10]. This study randomized 51 men with LUTS secondary to BPH to bipolar TUVP (n = 30) versus monopolar TURP (n = 21), of

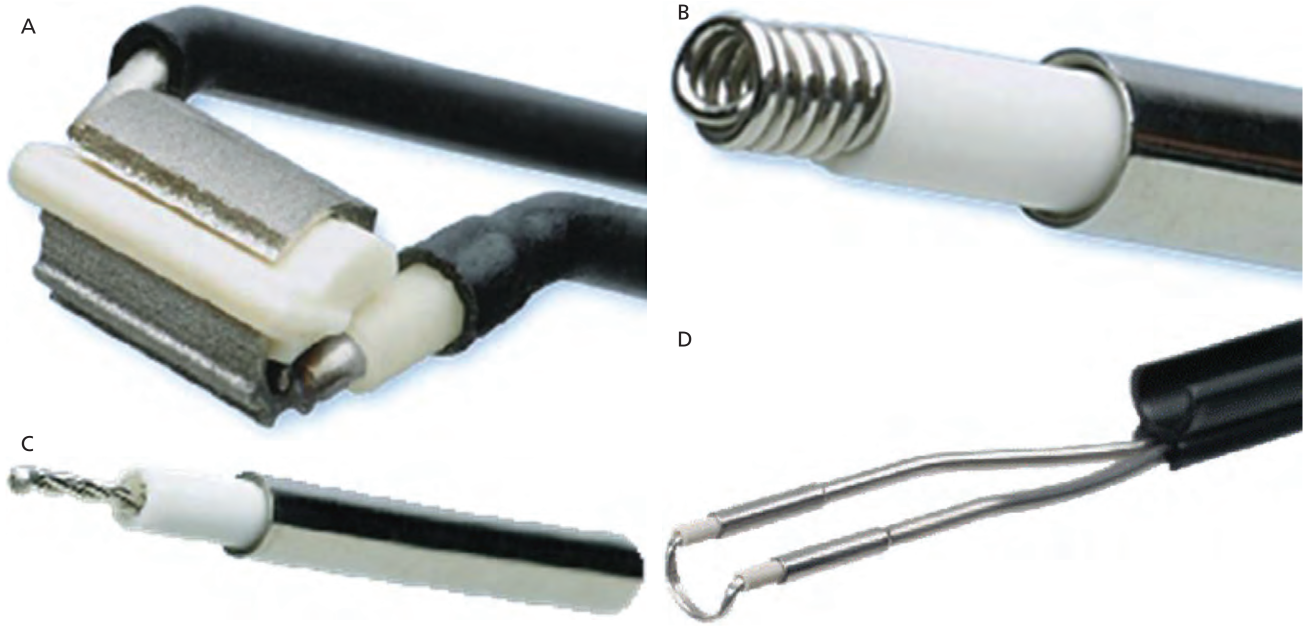

Figure 134.3 (A) PK ® Plasma-V PK "SuperPulse" Generator Vaporization Electrode (Gyrus, ACMI, Southborough, MA, USA), (B) PK PlasmaCise PK "SuperPulse" Generator Electrode (Gyrus, ACMI), (C)PK ® PlasmaCut PK "SuperPulse" Generator Electrode (Gyrus, ACMI), (D) PK SuperSect (Wider Surface Loop) Generator Electrode (Gyrus, ACMI). (Reproduced by permission of Olympus.)

which 40 (20 in each group) completed follow-up at 1 year. The bipolar TUVP arm underwent vaporization using a similar technique to that previously described using the Gyrus PK device with the Axipolaire electrode, and monopolar TURP was performed using standard techniques. In terms of perioperative outcomes, there was no difference in operative time, irrigation time, time to catheter removal, or length of hospital stay between the two groups. These patients were followed up 1-year later and improvements in IPSS, flow rates, PVR, and quality of life were similar between the two groups. Interestingly, four patients in the TURP group compared to zero patients undergoing TUVP required manual clot evacuation in the postoperative period, but the recatheterization rate for the TUVP procedure was 30% (compared to 5% for traditional TURP). All patients voided successfully 2–3 weeks later (range 14–19 days).

Hon *et al*. performed a randomized prospective clinical trial on 160 consecutive patients in their practice undergoing transurethral prostatectomy for bladder outlet obstruction [11]. They randomized the men to traditional TURP (n = 81) versus bipolar TUVP (n = 79) using the Gyrus PK system and the Plasma-V bar electrode. The two groups were similar preoperatively in regards to baseline characteristics. Mean operative time was 4 min shorter in the TURP arm, but this was not statistically significant (28.5 vs 32.6 min, $P = .08$). There was no significant difference between the two groups with respect to intraoperative blood loss; however, the TURP group had a greater hemoglobin decrease postoperatively (1.4 vs 0.8 g/dL, $P = .002$). Likewise, the TURP patients required more irrigant (28.3 vs 20.1 L, $P = .001$) and more manual bladder irrigations postoperatively (31 in 11 patients compared to 11 in seven patients who underwent TUVP, $P = .27$). The only difference in short-term adverse events included a total of 14 units of blood transfusion in the TURP arm compared to zero units of blood transfusion in the TUVP arm. The hospital stay was significantly longer for patients who underwent TURP compared to TUVP (3.4 vs 3.0 days, $P = .04$). Interestingly, despite rigorous preoperative screening, eight patients in the TURP arm were found to have prostate carcinoma detected on prostate chip histology. Long-term outcomes were available in 93% of the patients at a mean follow-up of 258 days. IPSS, quality of life, PVR, and Qmax improved significantly regardless of technique; however, there was no statistically significant difference detected in any of these categories other than for average urine flow when comparing TURP to bipolar TUVP. This fairly large trial with a decent length of follow-up concluded that bipolar TUVP has equivalent outcomes to monopolar TURP but with fewer earlier complications.

The disadvantage of bipolar TUVP is the lack of tissue for histologic processing. It is important to note that some clinically significant cancers may be missed, therefore highlighting the importance of screening these patients preoperatively and following them postoperatively with serial serum PSA and DRE.

Due to the potential for missing cancer and lack of tissue obtained from pure vaporization techniques, researchers began exploring a possible hybrid technique. This technique combined bipolar vaporization of the prostate with bipolar resection (TUVRP) and was described by Tefekli *et al.* in 2005 [12]. It should be pointed out that other researchers have shown that tissue sampling with a resection loop after vaporization of the prostate may not increase the likelihood of cancer detection [13]. In this randomized prospective clinical trial, 50 patients undergoing surgery for BPH were randomized to standard monopolar TURP and 51 patients were randomized to the hybrid bipolar TUVRP technique. The bipolar TUVRP procedure was performed with the Gyrus PK system using saline for irrigation. The lateral and median lobes were removed with a vaporization electrode and the final resection of tissue tags and apical tissue around the verumontanum were removed with a resecting loop. This technique was employed to not only remove tissue for pathologic analysis but also to aid delicate tissue resection around the apex and verumontanum. Complete data were available on 96 patients with a mean follow-up of 18.3 months (range 12–23 months). Mean operative time, catheterization time, and hospital stay were significantly lower in the TUVRP group compared to the TURP group. Mean improvement in Qmax was significantly better in the TUVRP group at 12 months, but mean improvement in IPSS from baseline was equivalent between the two groups. However, these authors did note an increase in irritative symptoms and recatheterizations in the TUVRP group, which they hypothesized was due to increased tissue edema due to the higher current with lower frequency exerted on the tissue. Of the three patients in the TUVRP group who required recatheterization, all were able to void after 7 days. The increased recatheterization rate paralleled the findings of Dunsmuir *et al*. [10]. Urethral stricture was also a more common complication in the TUVRP group (three TUVRP vs one TURP, $P = .002$) and was successfully managed endoscopically in all patients. The reoperation rate for persistent obstructive symptoms was not statistically significant, likely due to the low number of events in each group, with two patients in the TUVRP arm and only one in the monopolar TURP arm.

With several randomized prospective clinical trials emerging in the literature comparing bipolar TUVP to monopolar TURP, Neill *et al.* elected to compare holmium laser enucleation of the prostate (HoLEP) to bipolar TUVP in a randomized prospective clinical trial [14]. Forty patients were randomized 1:1 to either HoLEP or bipolar TUVP using the Gyrus PK device with the Axipolaire electrode. In their study, HoLEP performed better than TUVP in regards to mean operative times (43.6 min vs 60.5 min, $P < .05$) and fewer patients in the HoLEP arm required bladder irrigation (5% vs 35%, $P < .001$). The other outcomes analyzed, including hospital stay, catheterization time, complication rate, changes in IPSS, and maximum flow rate at 12-month follow-up, were all similar between the two groups. These authors concluded that bipolar TUVP has equivalent functional outcomes to HoLEP but increased intraoperative bleeding, which results in longer operative times and increased postoperative irrigation requirement. Surgeon preference, bias, and familiarity also play a large role and may have influenced these investigators to those conclusions.

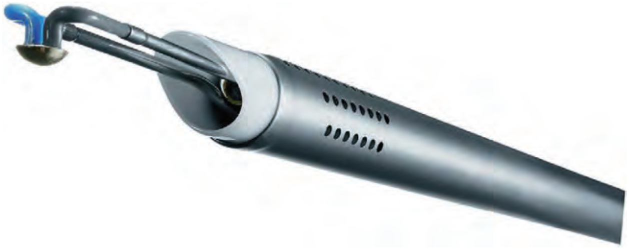

Figure 134.4 Bipolar mushroom-like electrode (reproduced by permission of Olympus Winter & Ibe GmbH, Hamburg, Germany).

As solid level 1 evidence showing the safety and efficacy of bipolar TUVP has mounted, investigators have continued to search for the optimal electrode for bipolar vaporization. Recently, Reich *et al*. reported on a novel mushroom-like electrode (Olympus Winter & Ibe GmbH) [7]. This pilot study utilized the UES-40 SurgMaster (Olympus Winter & Ibe GmbH) bipolar high-frequency generator, a 26F continuous flow resectoscope, normal saline as irrigant, and the aforementioned electrode (Figure 134.4). The vaporization technique is performed using the electrode in a near-contact technique (so-called *hoovering* technique). The procedure is otherwise performed like a traditional TURP, making the learning curve minimal (see Video 134.1). Thirty patients with BPH underwent bipolar TUVP using the mushroom-like electrode. The mean prostate volume was 59 mL (range 30–170 mL) and mean operative time was 61 min (range 20–140 min). No perioperative complications were noted, no patient required a blood transfusion, and no postoperative electrolyte abnormalities were noted. Postoperatively, four patients (13%) required recatheterization and the mean catheterization time was 41 h (range 18–192 h). Around half of the patients (53%) required continuous bladder irrigation postoperatively. The reoperation rate at 6-month follow-up was 3% (one patient required traditional TURP due to persistent obstructive symptoms). Transient mild-to-moderate dysuria was present in four patients (13%) and resolved within 2 weeks postoperatively with anti-inflammatory agents. Functional outcomes assessed at 6 months compared to baseline were excellent. Mean

Qmax increased from 6.6 mL/s at baseline to 18.1 mL/s at 6 months ($P < .01$). Mean IPSS decreased from 20.8 at baseline to 8.1 at 6 months ($P < .01$) and mean PVR decreased from 165 mL at baseline to 38 mL at 6 months ($P < .01$). This recently reported pilot study shows feasibility and acceptable short-term outcomes utilizing this novel electrode, and randomized prospective trials comparing this device to traditional monopolar TURP are underway.

Conclusions

Bipolar TUVP has been shown to be a safe and effective treatment for BPH through several well-performed randomized prospective clinical trials. Clearly, larger multicenter trials are needed with longer-term follow-up to assess long-term outcomes, specifically the reoperation rate and rate of urethral stricture occurrence. Certainly there is a role for bipolar TUVP in the toolbox of treatments available for BPH as urologists tackle larger prostate glands endoscopically and operate on sicker patients. Whether bipolar TUVP becomes widely accepted remains to be determined, especially in the face of stiff competition from high-powered lasers (holmium and KTP).

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CHAPTER 135

Single-Port Transvesical Simple Prostatectomy

Rene Sotelo, Camilo Giedelman & Mihir Desai

History

Open surgery has traditionally been the treatment of choice for benign, symptomatic prostatomegaly [1]. More than 2000 years ago, surgeons began using a median perineal incision for the removal of bladder calculi and in the first century of the classical era, surgeons used a semi-elliptical incision in this same perineal location for partial removal of the prostate. Although there are infrequent records documenting its use for a few hundred years, this perineal approach continued to be applied until 1894 when Eugene Fuller performed the first suprapubic prostatectomy. It was not until 1912, however, that the procedure was popularized as a result of Peter Freyer reporting his results with this technique, which consisted of the enucleation of the hypertrophic prostatic adenoma through an extraperitoneal incision of the lower anterior bladder wall. The next transition in surgical approach for treating benign prostatic hyperplasia (BPH) occurred over 30 years later, in 1945, when the retropubic simple prostatectomy was first described by Terence Millin. In 20 patients he reported a technique by which he achieved complete enucleation of the prostatic adenoma through a transverse capsulotomy incision on the anterior surface of the prostate gland. Subsequently, transurethral endoscopic techniques have virtually replaced the open approach in the surgical management of the majority of cases of BPH [2].

Recent developments in laparoscopic simple prostatectomy

Currently, despite the development of transurethral surgery and new technologies employed with this access, open surgery continues to be the ideal treatment for large adenomas in terms of its cost-effectiveness for this pathology. Modifications of the gold-standard transurethral resection have been incorporated into clinical practice and include bipolar transurethral resection, as well as holmium laser resection and potassium titanyl phosphate (KTP) laser vaporization. Minimally invasive ablative techniques have also been popularized and include transurethral needle ablation and thermotherapy [2].

Over the last decade, with the advent of laparoscopic and robotic surgery, new treatment alternatives have also begun to be used. In 2002, Mariano *et al.* described a technique for laparoscopic simple prostatectomy [3], which was reproduced with some modifications and then performed with robotic assistance. This basically duplicates the techniques of open surgery and maintains the standard of open surgery in regard to the proportion of tissue extracted, but with all the benefits associated with this type of minimally invasive surgery [4, 5].

Given that the ease of implementation of natural orifice transumbilical endoscopic surgery (NOTES) surgery is currently limited by the technologic equipment available, an intermediate alternative has been suggested in an attempt to further reduce the morbidity of laparoscopic surgery and improve its cosmetic results. This alternative is the use of a single access point into the abdominal cavity through the umbilical scar. This approach has been given different names, including E-NOTES (embryonic natural orifice transumbilical endoscopic surgery), NOTUS (natural orifice transumbilical surgery), SPA (single port access), and LESS surgery (laparoendoscopic single-site surgery). LESS is the use of endoscopic and laparoscopic techniques

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through a unique small incision using a single device that allows for the introduction of various instruments [6]. We began to explore the possibilities of applying this new access method to our technique of laparoscopic simple prostatectomy, first through the umbilicus and later through a small suprapubic incision that is used to place the port directly into the bladder. The operation was developed as a collaboration between Drs Gill and Desai and our group. In this chapter, we will describe the technique in detail, highlighting tips that may be useful in performing the surgery. We will also discuss the results obtained up until this point.

Single-port transvesical enucleation of the prostate

LESS adenomectomy can be performed by placing a single-port device in the umbilicus with a transperitoneal approach. This is challenging, because the bladder must be dropped and the finger cannot be used to assist the enucleation. Additionally, at the end of surgery, the cystotomy incision has to be closed laparoscopically in a water-tight manner. With the new double-bend instruments, this method has been made easier, but it is still inherently difficult to carry out.

Another option is to place the port directly through the bladder (Figure 135.1). In this manner, the bladder does not need to be dropped. Also, the finger can be used to assist the enucleation. At the end of surgery, the cystotomy closure can be done in a standard open fashion.

The laparoendoscopic transvesical simple prostatectomy is performed through a small incision of 2.5–3 cm, located 3 cm from the pubic symphysis, through which the device (R-port, Triport) is directly inserted. This device has two particularly important qualities: first, is has multiple flexible valves that do not protrude into the cavity and allow introduction of curved instruments; and second its valvular component is easy to open and does not need to be taken out to be changed, a crucial aspect in intraluminal surgery. Increasing interest in LESS surgery has come with the introduction of new instruments, such as the 5-mm flexible EndoEye (videoscope (Olympus, Tokyo, Japan) with its excellent image, and flexible, curved instruments that permit laparoscopic dissection and intracorporeal suturing [7].

Indications and contraindications

Single-port transvesical enucleation of the prostate (STEP) is indicated for patients with large prostates of greater than 70 g, as evaluated by transurethral ultrasound (TRUS).

Absolute contraindications to STEP include the presence of prostate cancer, morbid obesity, anticoagulation therapy, and anesthetic contraindications. Relative contraindications include the need for concomitant procedures such as hernia repair and bladder diverticulectomy. Another relative contraindication is prostates larger than 200 g.

Preoperative preparation

Preoperative evaluation must include history and physical examination. Also, digital rectal examination and routine laboratory tests are required, including prostate-specific antigen (PSA), International Prostate Symptom Score (IPSS), quality-of-life (QoL) questionnaires, uro-

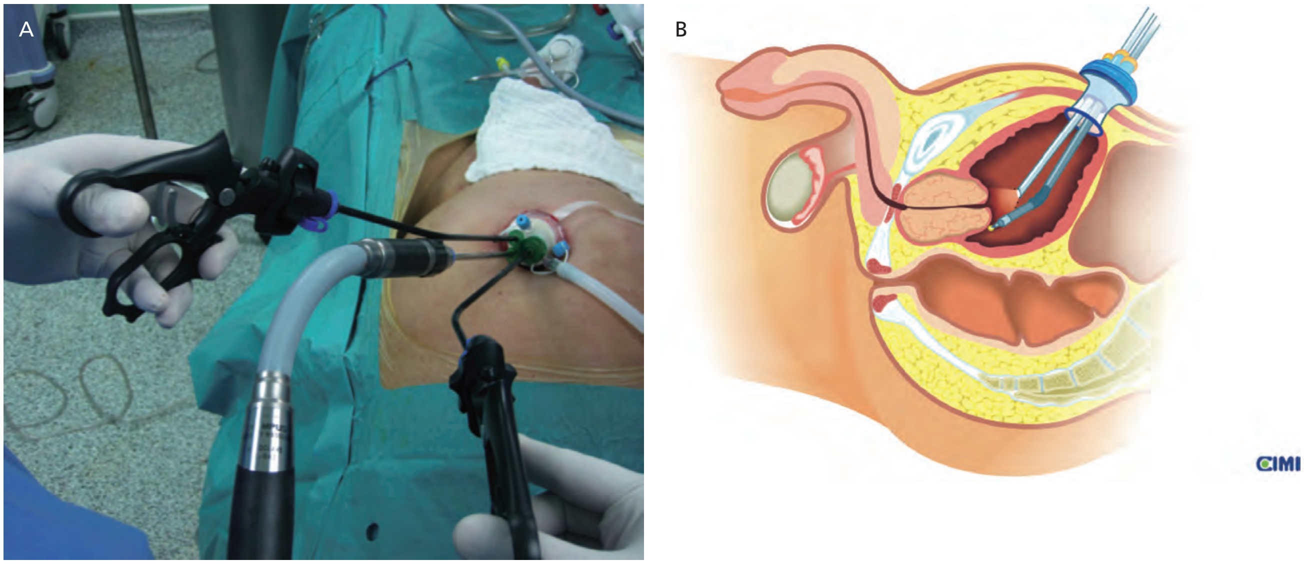

Figure 135.1 (A, B) Port placement directly through the bladder.

flowmetry, and TRUS evaluation of prostate volume and presence of the middle lobe. Urine should be cultured and preoperative antibiotics given. In cases where there is evidence of previous hematuria, acute urinary retention or urinary lithiasis, and cystocopy should be performed. Patients should stop taking Aspirin or any anticoagulant at least 8 days before surgery.

Surgical technique

The equipment and instruments required are listed in Table 135.1.

The Triport is a multiport access device that allows several instruments to pass simultaneously. It consists of a retractor and a valve. The retractor has an interior ring, two exterior rings, and a plastic retractable sleeve. The valve has three openings (two of 5 mm and one of 12 mm) for laparoscopic instruments and a port for inflation. The valve contains a thermoplastic elastomer that allows for the proper introduction of the instruments, including needles, with insignificant air loss.

Surgical steps

The advantages and disadvantages of this procedure are summarized in Table 135.2, and the key points in Table 135.3.

Table 135.1 Equipment and instruments required for single-port transvesical simple prostatectomy.

Equipment
Laparoscopic video tower (21-inch monitor, EXERA II image processor with light source)
Video laparoscope: EndoEye (Olympus, Tokyo, Japan), 5-mm, 30° lens
UHI-3 high-flow CO_2 inflator (up to 35 L/min).
Ultrasonic generator
Electrosurgical unit (monopolar/bipolar)
Aspiration–irrigation pump
Flexible cystoscope

Instruments to develop the procedure
Triport (Advanced Surgical Concepts, Wicklow, Ireland/Olympus).
5-mm flexible articulating instruments: scissors (Cambridge Endo, Framingham, MA, USA)
5-mm J hook electrocautery instrument
Ultrasonic 5-mm shears
5-mm suction–irrigation cannula, pre-bent
Carter–Thomason device
Two laparoscopic needle holders
Silicone three-way 22F and two-way 24F Foley catheters, in case a suprapubic tube is needed.
Sutures: Monocryl 0 with CT-1 needle for adenoma traction, and 2/0 with CT-1 needle for ligature of lateral pedicles and trigonization (the monofilament facilitates the extracorporeal knotting)
Sotelo prostatotomy device
Knot pushers

Table 135.2 Advantages and disadvantages of single-port transvesical simple prostatectomy.

Advantages
- Pneumovesicum maintains a broad field of work
- Allows the observation of all anatomic details of the bladder, prostate, and urethra during each step of the surgery.
- Lower risk of intestinal injury and lower likelihood of development of postoperative ileus
- Easy opening of the device allows the extraction of fragments during surgery. Furthermore, it allows the introduction of a finger if necessary to remove the adenoma
- Due to the fact that the adenoma fragments are confined in the bladder and are not released in the abdominal cavity, extraction pouches are not necessary

Disadvantages
- Steep learning curve. At first, enucleation is difficult, but the location of the suprapubic incision allows bimanual dissection if necessary. The index finger of the left hand in the rectum elevates the prostatic fossa and the index finger of the right hand through the ring of the Triport helps the mobilization of the adenoma

Table 135.3 Key points in the procedure.

- Placement of a traction suture through the full thickness of the bladder using absorbable material. The same stitch will enable placement of subsequent stitches, which will facilitate introduction of the trocar and the closure of the defect at the end of the case
- It is important to lubricate the entrance of the Triport in order to facilitate entry of instruments through the membranes, as well as facilitating the introduction of the videoscope and its rotational movement
- The incision should be made between the adenoma and the mucosa of the bladder. The surgeon can observe a faint change in color. This serves as a reassuring reference point
- If problems arise in the traction of the adenoma, the suture can be exteriorized through the abdominal wall with the assistance of a Carter–Thomason device
- A useful tool designed specifically for prostatic adenomectomy is the Sotelo prostatotomy device. This consists of three parts: a Teflon sleeve, a stainless steel cylinder body, and a curved shape with sharp edges at the distal end
- It is important to note that, if necessary, the surgeon can convert the procedure to a standard laparoscopic surgery with the addition of more trocars as necessary

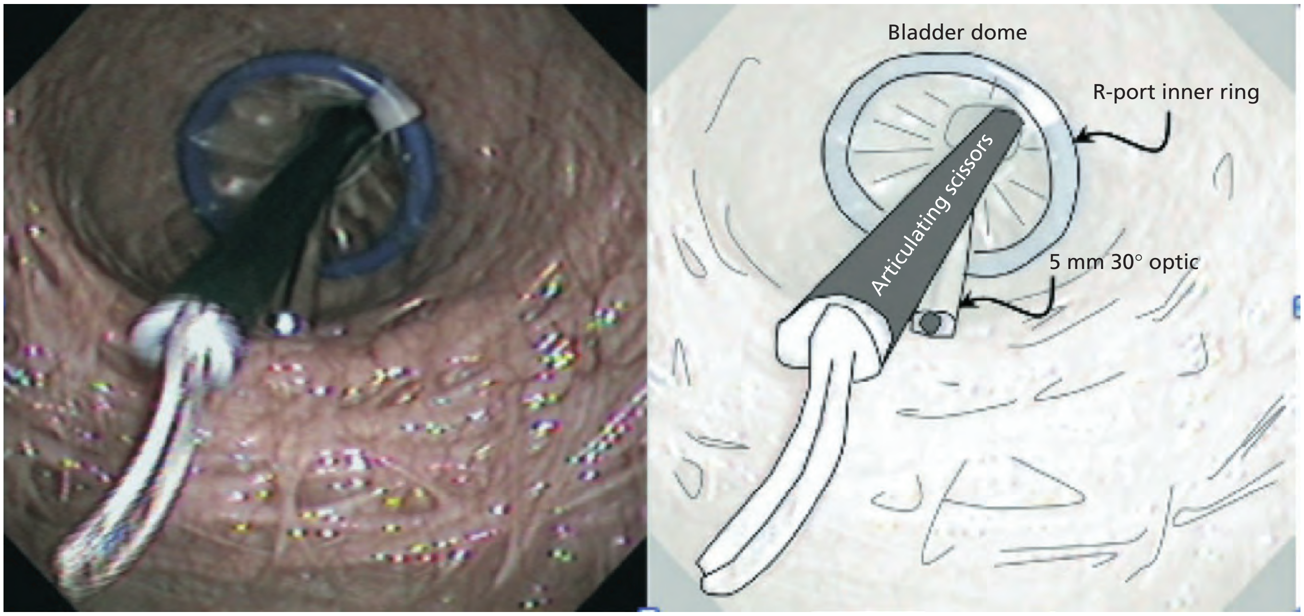

Figure135.2 Insertion and deployment of the R-port under cytoscopic guidance.

Patient position and endoscopic evaluation

All procedures are performed under general anesthesia with the patient in a modified low-lithotomy position. Initially, cystoscopy is performed and the prostate evaluated endoscopically. The bladder is filled with normal saline solution.

Insertion and deployment of the Triport

An approximately 2.5-cm skin incision is carried down to the rectus fascia. The incision is located just above the pubis. The bladder wall is identified and cleared of any prevesical fat. Two stay sutures of 2-0 Vicryl are placed.

The bladder wall is entered sharply between the stay sutures, and the inner ring of the Triport is inserted into the bladder, being deployed with the help of an introducer. The inner and outer rings are approximated by removing the slack on the plastic sleeve, thus cinching the abdominal and bladder walls between the rings of the Triport in an airtight seal. The valve of the Triport is inserted and the bladder insufflated with CO_2 to create the pneumovesicum. The insertion and deployment of the R-port is monitored cystoscopically (Figure 135.2).

The use of absorbable material for stitches in the bladder is important. These pass through its entire thickness, one in front of the other. The stitches serve as the anchor for traction and also facilitate the introduction of the trocar. They are also tied together to close the defect upon completion of the surgery.

Care must be taken that the incision in the fascia and the bladder is no more than 2.5 cm. This is because otherwise the inner ring of the Triport will be dislodged. In Figure 135.2, the inner ring of the Triport is seen outside of the bladder.

Mucosal incision and enucleation

A large, bulging median lobe can be retracted anteriorly in an efficacious manner with a figure-of-eight stay stitch. This can be placed with a Keith needle or Carter–Thomason port closure needle device. The two ends of the stay stitch are retrieved and anchored outside of the anterior abdominal wall.

A Monocryl suture on a CT-1 needle is placed through the adenoma for retraction purposes (Figure 135.3A).

A U-shaped incision is made over the bladder mucosa, immediately overlying the adenoma, from the 3 o'clock to the 9 o'clock position, and through the 6 o'clock position. Typically, a reddish zone of mucosa is seen immediately lateral to the internal meatus. This serves as a reliable guide for creating the mucosal incision. The horizontal limb of the U-incision is made using a hook electrode and cutting current to reach the adenoma. The whitish prostatic adenoma is readily identified. The plane between the surgical capsule and the adenoma is created using a hook and suction cannula. The two limbs of the U-incision are created, followed by completion of the circumferential mucosal incision (Figure 135.3B).

Separate excisions of each mobilized lobe of the adenoma provide superior visualization of the remaining part of the adenoma, enabling better hemostasis.

Several maneuvers are used to facilitate the enucleation of the adenoma:

- The valve is removed first and then the right index finger is inserted through the Triport. This expedites the distal part of the enucleation. The left index finger is placed into the rectum to elevate the prostate. Once the finger dissection has been completed, the Triport valve

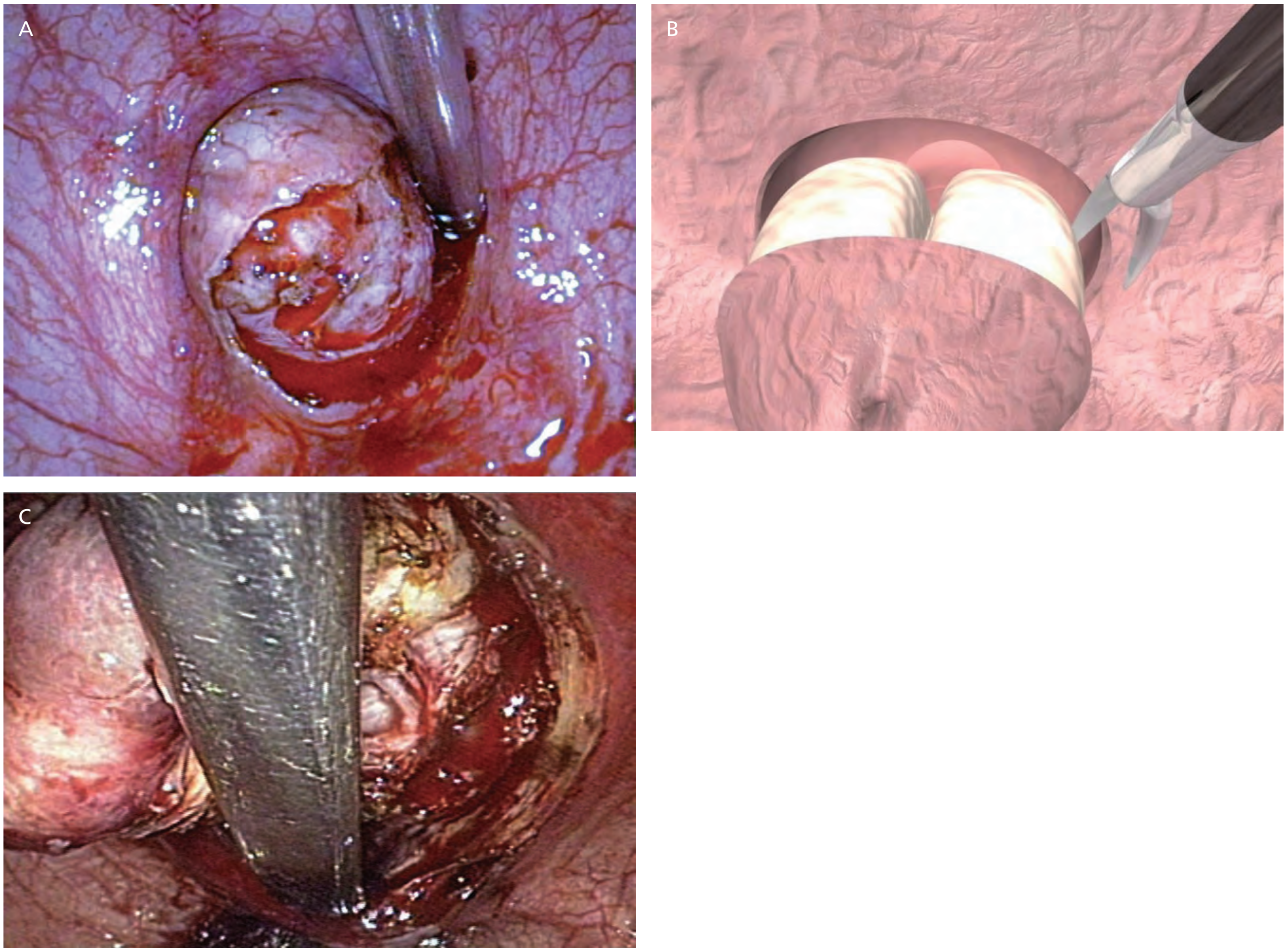

Figure 135.3 (A) A Monocryl suture on a CT-1 needle is placed through the adenoma for retraction. (B) Mucosal incision and enucleation. (C) Division of prostatic adhesions.

is reattached. The pneumovesicum is re-established for incising the urethra at the prostatic apex and completing the procedure.

- Use of the "Sotelo prostatotomy," a device similar to a curette or an osteotome, facilitates enucleation of the adenoma during laparoscopic simple prostatectomy. Its metallic, curvilinear tip, with a sharp cold knife on the distal side of the forceps, is used to divide the adhesions between the adenoma and its capsule during circumferential dissection of the gland (Figure 135.3C).
- The urethra is incised with a bipolar resectoscope through the urethra, immediately after the placement of the port and before any dissection from above (Figure 135.4).

Hemostasis

After removing the adenoma, hemostatic figure-of-eight sutures are tied down with an extracorporeal knot pusher and must be placed at the 4 and 8 o'clock positions at the prostatic capsule, to control the main prostatic vessels (Figure 135.5).

The lateral pedicles of the prostate should be thoroughly checked and the pneumovesicum pressure diminished to ensure that there is no bleeding. In the event that there is slight bleeding, it can be controlled with a monopolar or bipolar unit. If there is still any doubt, stitches can be made with absorbable sutures and knotted extracorporeally.

Specimen extraction

The prostatic adenoma is extracted through the Triport ring after dividing it into multiple pieces during extraction with Allis forceps (Figure 135.6).

Trigonization and closure of the bladder

After adenoma removal, trigonization of the prostatic fossa can be performed by suturing the cut end of the posterior bladder neck distal toward the apex of the prostatic fossa. This can be tied down with an extracorporeal knot pusher.

The bladder opening is sutured with 3-0 Vicryl, and the fascia and skin are closed in a standard fashion.

Depending on the amount of bleeding, a suprapubic catheter can be inserted through the inner ring of the Triport (Figure 135.7). The balloon should be inflated before the Triport is removed. The ring of the Triport is large enough to pass the distal part of the catheter. In this way, it is easier to ensure that the Foley catheter is inside the bladder (Figure 135.8). Thus, the first Vicryl stay suture, which was previously placed in the bladder, can be tied, along with any additional sutures, to give a water-tight closure.

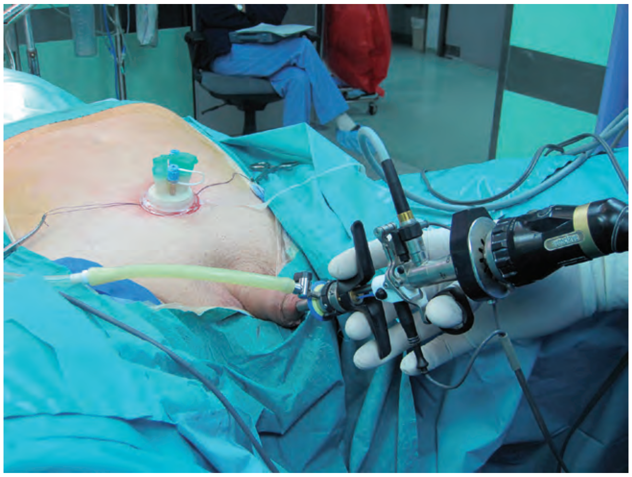

Figure 135.4 Incised of the urethra with a bipolar resectoscope.

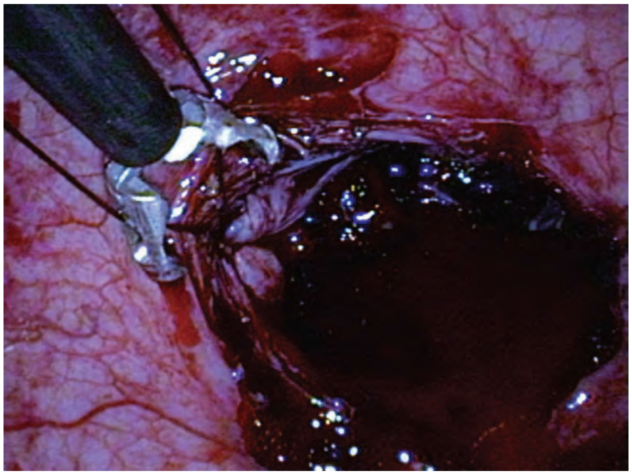

Figure 135.5 Hemostasis of the main prostatic vessels with figure-eight sutures. These are tied down with an extracorporeal knot pusher and must be placed at the 4 and 8 o'clock positions of the prostatic capsule.

Postoperative management

Close monitoring of urine drainage is important to ensure it remains clear. It is routine to verify the postoperative hematocrit. Continuous bladder irrigation should be initiated to prevent clot formation. If significant hemorrhage is noted, the urethral catheter may be placed on traction so that the balloon can compress the bladder neck and prostatic fossa. On average, continuous irrigation is removed 12 h after verification that there is no bleeding.

On the same day as surgery, the patient can start a liquid diet. On the first postoperative day, the patient starts ambulation and a regular diet; oral analgesics can be given and parenteral narcotics are discontinued.

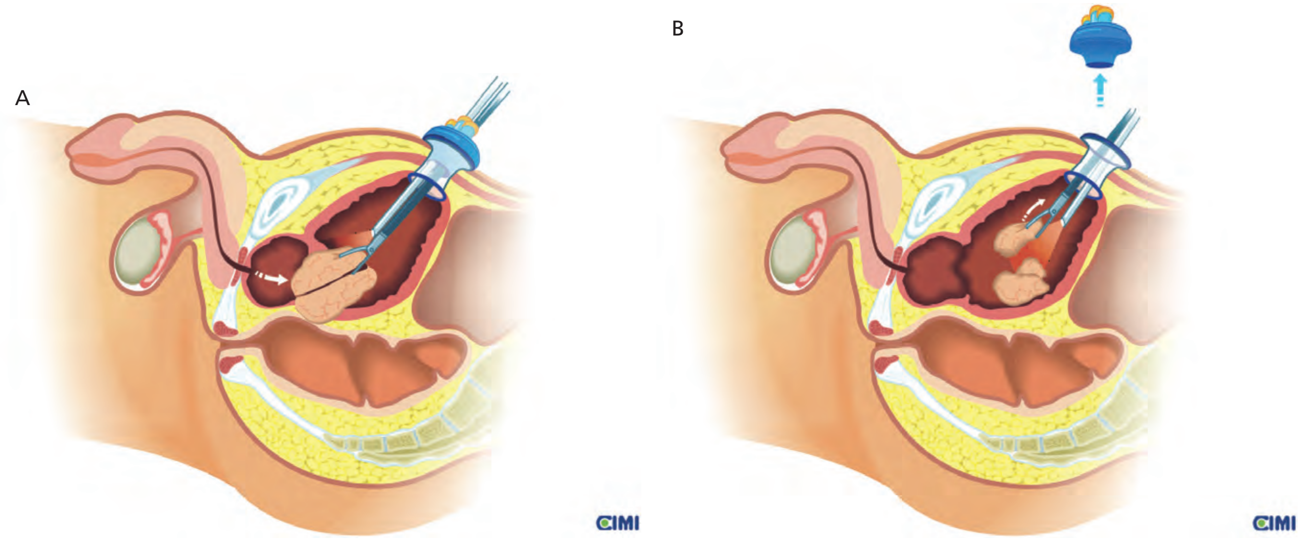

Figure 135.6 (A, B) Prostatic adenoma is extracted through the Triport ring after dividing it into multiple pieces during extraction with the Allis.

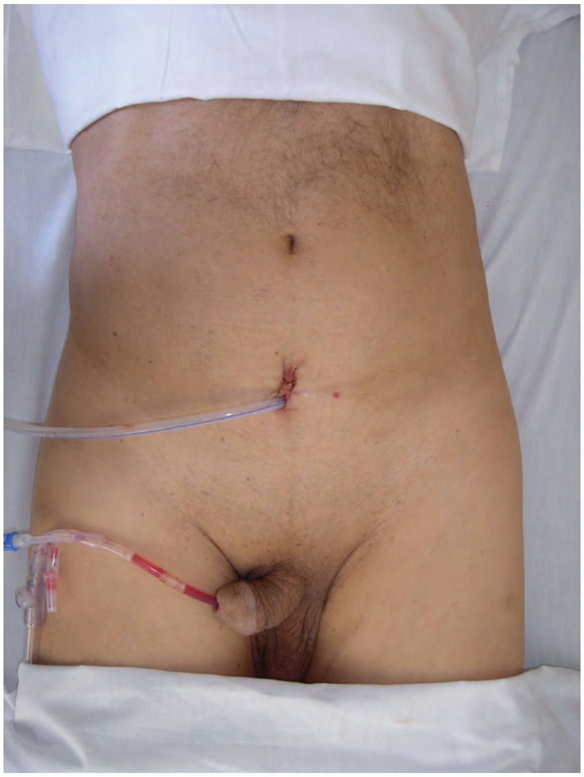

Figure 135.7 Insertion of a suprapubic catheter through the inner ring of the Triport.

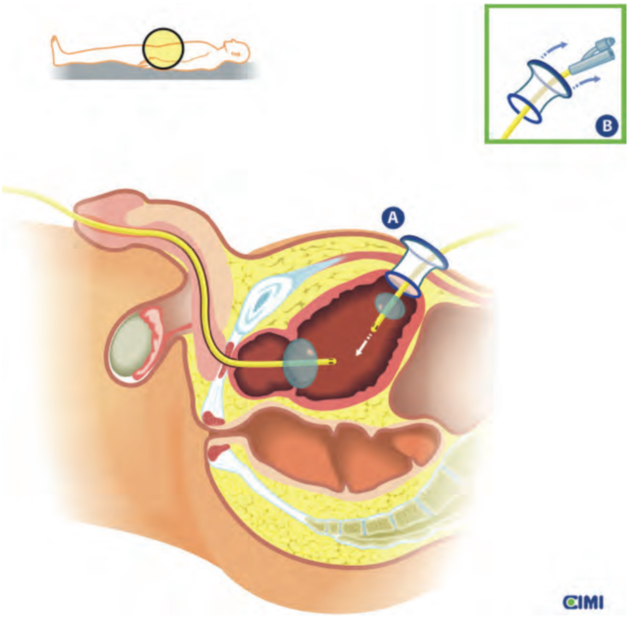

Figure 135.8 Ring of the Triport is large enough to pass the distal part of the catheter. This is the easiest way to ensure the Foley catheter is inside the bladder.

Usually the patient is discharged 24 h after the procedure with appropriate discharge instructions.

The Foley catheter is removed within 5–7 days. If a cystostomy has been left, it is generally removed within 48 h.

Complications

The overall rate of morbidity associated with single-port transvesical simple prostatectomy is extremely low; and to date no case of mortality has been encountered. Also, to date there have been no reports of stress incontinence, erectile dysfunction or thromboembolic events related to surgery. Stress incontinence and total incontinence are rare even for open surgery; with precise enucleation of the prostatic adenoma, the risk of injury to the external sphincter mechanism is minimal. The incidence of urinary extravasation is practically zero with this technique because the incision through the bladder is very small, less than 2.5 cm.

The most common problem is hemorrhage, usually arising from venous structures.

Following surgery, urgency and urge incontinence may be present for several weeks, depending on the preoperative bladder status. An anticholinergic agent can help to resolve these symptoms.

Results

Our early follow-up data show that prostatic adenoma was successfully enucleated in all of 23 patients using this novel single-port transvesical technique [8]. Their mean baseline PSA was 6.6 ng/mL (1.02–23 ng/mL), IPSS 21 (11–31), and TRUS prostate size 90 mL (51–247 mL).

The mean operative time was 100 min (45–210 min) and estimated blood loss was 400 mL (50–1500 mL). Three patients (13%) were transfused. Complications were present in four patients, including the three who were transfused. One patient had an inadvertent enterotomy during port insertion that was subsequently recognized and fixed intraoperatively by open conversion after BPH enucleation had been completed laparoscopically. This patient had a history of previous exploratory laparotomy through a full midline incision for colon cancer and subsequent incisional hernia repair. A suprapubic catheter and a drainage tube were placed for safety, and the patient recovered uneventfully with a hospital stay of 3 days.

The duration of hospitalization was 2 days on average, and the Foley catheter was removed on postoperative day 7 in most of the patients. All patients were voiding spontaneously without a significant postvoid residual volume and were fully continent. The mean postoperative peak urinary flow rate after catheter removal was 41 mL/s (13–84 mL/s).

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CHAPTER 136

Bladder Injections for Refractory Overactive Bladder

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Introduction

Idiopathic overactive bladder (I-OAB), as defined by the International Continence Society, is “urgency, with or without urge incontinence, usually with frequency and nocturia, [when] there is no proven infection or obvious pathology” [1]. Using this or a slightly older definition, the prevalence of I-OAB in Europe and the USA has been found to be 12.8–16.6%, with about one-third of these patients having incontinence [2–5]. Studies show I-OAB leads to deterioration in quality of life (QoL) in about 50% of patients, with the proportion increasing to 80% in those with incontinence [6]. Furthermore, these patients may experience other detrimental medical effects as a result of I-OAB, such as falls and fractures from multiple trips to the restroom, urinary tract and skin infections, sleep disturbances, and depression [7]. Additionally, patients with neurologic disorders, such as multiple sclerosis, myelomeningocele, and spinal cord injury, often experience voiding dysfunction. When this voiding dysfunction is consistent with OAB, it is termed neurogenic overactive bladder (N-OAB) [8].

The mainstay of treatment for OAB has been pelvic floor rehabilitation/behavioral therapy and anticholinergic/antimuscarinic medication, as cholinergic receptors in the bladder, stimulated by acetylcholine released from parasympathetic neurons, are responsible for bladder contraction during voiding [9, 10]. However, such receptors exist elsewhere in the body, including the brain, salivary glands, heart, gastrointestinal tract, and eyes, resulting in side effects: cognitive problems, dry mouth, tachycardia, constipation, and blurred vision. Such side effects, and a relative lack of efficacy, have led to discontinuation of anticholinergic medication in 35–45% of patients [11, 12]. Almost half of patients discontinued medication as they felt it “did not work as expected,” and almost one-fourth of patients blamed the side effects [13]. Therefore, alternative methods for treatment of OAB in patients refractory to anticholinergic medications and behavioral treatments are needed and are being actively explored.

Injection of botulinum toxin A (BTX-A) into the detrusor wall of patients with refractory OAB has shown some success and is the focus of this chapter; however, alternative approaches include sacral neuromodulation and intravesical instillation of vanilloid receptor agonists such as resiniferatoxin [14, 15].

Mechanism of action

BTX is a potent neurotoxin produced by the anaerobic bacterium *Clostridium botulinum*, that can result in severe symptoms following ingestion of infected, improperly stored foods or infection of a wound. Symptoms of poisoning with BTX (mydriasis and progressive neuromuscular paralysis resulting in muscle weakness, dyspnea, and possibly death) were first described in the 1820s by the German physician Kerner, who observed an outbreak among soldiers suffering “sausage poisoning” from eating, at that time unknowningly, infected sausages [16]. It was not until 1897 that the microbiologist van Ermengem discovered the culprit bacterium that he termed “bacillus botulinus” (from the Latin word *botulus* meaning sausage) after isolating it from the tissue of several people who died following a funeral dinner as well as the smoked ham served that day [17]. The first

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medical application of BTX was by Scott in 1977, an ophthalmologist who treated patients with strabismus or blepharospasm, and Food and Drug Administration (FDA) approval for this application was granted in 1989 [18]. Further uses of BTX approved by the FDA include cosmetic applications, treatment of excessive underarm sweating, and cervical dystonia.

Different types of BTX exist from A to F, based on specific interaction with different SNARE proteins that are required for release of acetylcholine from the presynaptic terminals, resulting in inhibition of cholinergic and neuromuscular synapses and subsequent decreased or absent muscle contractions [19].

Theories of the pathophysiology of OAB include lack of inhibition by upper motor neurons in patients with N-OAB, and over sensitivity of sensory fibers and reflex pathways in patients with I-OAB. BTX has been shown to both block these afferent fibers, resulting in a decreased sensation of fullness, and the efferent fibers responsible for the reflex bladder contractions, therefore significantly decreasing smooth muscle contractility [20–22]. BTX-A has the longest duration of action, followed by BTX-B, and these have become the focus of medical applications. Two different preparations of BTX-A exist: Botox, available in the USA, and Dysport, available in the remainder of the world. Formulations of BTX-B include Myobloc in the USA and Neurobloc in Europe.

Results for botulinum toxin a injections

Although BTX was initially thought to work only on striated muscle fibers, the efficacy of injection of BTX into the detrusor smooth muscle of the bladder wall of patients with refractory N-OAB was first demonstrated by Schurch *et al*. in 2000 [23]. In 21 patients with spinal cord injury, experiencing incontinence secondary to neurogenic detrusor overactivity, requiring clean intermittent catheterization (CIC) to empty, and having failed anticholinergics, they demonstrated a significant increase in mean maximum bladder capacity (from 296 to 480 mL, $P < .016$) and a significant decrease in mean maximum detrusor voiding pressure (from 65 to 35 cmH_2O, $P < .016$). Of the 21 patients, 17 were completely continent at 6-week follow-up and were satisfied with the procedure; improvements in urodynamic parameters and incontinence persisted at 36 weeks in 11 patients [23]. Since that initial description, many studies have demonstrated the utility of BTX injection as an appropriate second-line therapy for patients with OAB refractory to anticholinergics (Table 136.1) [24–42]. A Cochrane review also concluded that BTX-A was superior to placebo, with resulting increased capacity, decreased pressure, improved QoL, and incontinence, with higher doses being more effective [43]. Improvements in symptoms and QoL have also been described to occur to the same degree in patients with I-OAB and N-OAB, but will be described separately for simplification of comparison of different trials [44, 45].

Neurogenic overactive bladder

Two randomized, placebo-controlled trials evaluating the efficacy of BTX in patients with N-OAB have been reported (Table 136.1) [27–29]. Ehren *et al*. randomized 31 patients (17 males, 14 females) to injection of 500 U Dysport or placebo, and evaluated cystometric and QoL outcomes at 6, 12, and 26 weeks [29]. They demonstrated a statistically significant increase in bladder capacity over placebo at 6 and 12 weeks, and a decreased detrusor pressure and number of incontinent episodes throughout the trial. Additionally, patients treated with Dysport had a significant reduction in their use of tolterodine. In another trial by Schurch *et al*., 59 patients with N-OAB (36 males, 23 females) were randomized to receive Botox (300 or 200 U) or placebo, and followed at 2, 6, and 24 weeks with cystometry and QoL measures [27, 28]. Incontinent episodes were significantly decreased and QoL was improved in both treatment groups, but these parameters were unaffected in the placebo group. Cytometric measures also revealed a significant increase in bladder capacity and decrease in bladder pressures only in the treatment groups.

Further large-scale open-label trials have demonstrated the efficacy of BTX-A (either Botox or Dysport) with 68–95% improvements in incontinent episodes (Table 136.1) [30, 32]. Two studies achieved continence in about 75% of patients and were able to increase bladder capacity by 28–54% and decrease pressure by 44–52% between 1 and 3 months [31, 33].

Idiopathic overactive bladder

There have been three randomized, placebo-controlled trials of the efficacy of BTX in patients with I-OAB. Sahai *et al*. randomized 34 patients with I-OAB (15 men, 19 women) who had failed at least 6 weeks of anticholinergics to receive either 200 U of Botox or placebo and followed them at 4 and 12 weeks with cystometry and QoL measures [34, 46]. Cystometry in the Botox-treated patients revealed significant increases in maximum capacity, from 181 to 313 mL at 4 weeks and 264 mL at 12 weeks, in comparison to a decreased capacity in the placebo group from 198 mL at 4 weeks to 168 mL at 12 weeks. Patients treated with Botox had a significant reduction in urinary frequency and urge incontinence, and QoL scores improved 52%, while placebo patients did not realize any improvements in QoL measures [34, 46]. Of 16 patients in the treatment

Table 136.1 Trials injecting botulinum toxin into the detrusor wall of patients with overactive bladder (OAB) refractory to medication.

Study	N	Drug	Evaluation time points	Urinary incontinence (%)*	Capacity (ml) (pre/post/% change)*	Pdet max (cmH$_2$0)* (pre/post/% change)*	Residual volume (mL) (pre/post/% change)&	QoL (% change)*
Neurogenic OAB								
Randomized controlled trials								
Ehren *et al.* [29]	31	Dysport 500 Placebo	6, 12, 26 weeks	–48 IE NA	**+37.5% **+5%	**-69% **–20%	NA	NA
Schurch *et al.* [27, 28]	59	Botox 300 Botox 200 Placebo	2, 6, 12, 18, 24 weeks	–32 IE –58 IE –3 IE	294/398/+35 260/441/+69 255/301/+18	92.6/55.2/–40 77/48.8/–36 79.1/80.6/+2	NA	+51 +77 +4
Open label trials								
Reitz *et al.* [31]	231	Botox 300 U	12 weeks 36 weeks	+73 TC	272/420/+54 272/352/+29	61/30/–44 61/44/–28	NA	NA
Del Popolo *et al.* [30]	199	Dysport 500, 750, 1000 U	4 weeks	–95 IE	230/409/+87	NA	NA	NA
Giannantoni *et al.* [32]	23	Botox 300 U	3 months	–63 IE	246/459/+86.4	62.3/24.6/–61	NA	NA
Pannek *et al.* [33]	27	Botox 300 U	4 wks	+78 TC	317/406/+28	52.6/21.9/–52	NA	NA
Idiopathic OAB								
Randomized controlled trials								
Sahai *et al.* [34]	36	Botox 200 U Placebo	4, 12 weeks	–70 IE –19 IE	182/264/+45 198/168/–15	86/44/–49 79/79/0	44/51/+16 23/23/0	+52 –5
Brubaker *et al.* [35]	43	Botox 200 U Placebo	4 weeks	–76 IE –5 IE	NA	NA	NA	+38 0
Flynn *et al.* [36]	22	Botox 200/300 U Placebo	3, 6 weeks	–57 IE +9 IE	NA	NA	25/107/+328 30/27/–10	+47 –7
Open-label trials								
Khan *et al.* [37]	74	Botox 200 U	4 weeks	+50 TC, –67 UF	NA	NA	NA	NA
Schmid *et al.* [38]	100	Botox 100 U	4, 12 weeks	+80 TC, –50 UF	**+56%	NA	NA	NA
Jeffery *et al.* [39]	25	Dysport 500 U	3 months	–56% IE, –27 UF	309/367/+19	NA	36/88/+144	+40
Pediatric OAB								
Schulte-Baukloh *et al.* [40]	20	Botox 12 U/kg (max 300 U)	1 months 3 months 6 months	NA	163/220/+34 163/201/+20 163/222/+35	59.6/35.9/–61 59.6/46.7/–22 59.6/61.6/+3	NA	NA
Kajbafzadeh *et al.* [41]	26	Botox 10 U/kg	4 months	+73 TC	103/270/+162	139/83/–40	NA	NA
Riccabona *et al.* [42]	15	Botox 10 U/kg	3 months 6 months 9 months	+86.7	136/297/+115 136/284/+110 136/154/+13	78.8/42.8/–45 78.8/48.3/–39 78.8/77.7/–1	NA	NA

*Values in different rows within the same study are based on drug or placebo in randomized controlled trials, or different time points of evaluation (if multiple time points are present, but there is only one row of data, then the latest time point of evaluation is used).

**Approximations as raw numbers unavailable.

NA, not analyzed; IE, incontinent episodes; TC, total continence; UF, urinary frequency; Pdet, detrussor pressure.

group, six (37.5%) required CIC on a temporary basis for increased postvoid residual (PVR) volume greater than150 mL. Another study of 43 women with I-OAB by Brubaker *et al*., randomized patients in a 2:1 manner to injection with 200 U Botox or placebo [35]. The primary outcome in this trial was time to failure, defined as a response to the Patient Global Impression of Improvement (PGI-I) of no change or worse. Approximately 60% of the Botox group demonstrated clinical improvement on PGI-I with a median duration of 373 days. One month after injection, there was a significant decrease in the number of incontinent episodes in the Botox group only and QoL improved 35% compared to no improvement with placebo. CIC was needed in 43% of the Botox patients for a median of 62 days. Flynn *et al*. randomized 22 patients with I-OAB and incontinence to placebo or Botox (200 or 300 U) and followed them at 3 and 6 weeks. After 6 weeks, the Botox group experienced a decrease in urogenital distress inventory (UDI)/incontinence impact questionnaire (IIQ) of 37%, while the placebo group actually experienced an increase of 7% (i.e. they worsened); there was an increase in PVR from 25 mL to 107 mL in the Botox group [36].

Results from these initial trials were further explored in large prospective trials (Table 136.1). Following treatment with BTX, overall urinary frequency was decreased in 27–67% of patients at 1–3 months, with complete resolution of incontinence in 50–80% of patients [37–39, 47, 48]. Elderly patients (75 years of age or older, mean 81.2 years) with I-OAB have also been shown to benefit from BTX in one study, with 76.2% having a greater than 50% improvement in symptoms [49]. No urodynamic study or demographics factor has been able to predict response to BTX injection in patients with I-OAB [50, 51].

Pediatric overactive bladder

Pediatric patients with myelomeningocele experience difficulty with bladder function, and many suffer from detrusor overactivity and incontinence. Additionally, there is concern for deterioration of their upper tracts as they may have high bladder pressures due to poor or intermediate compliance and vesicoureteral reflux. Several nonrandomized studies have been carried out in children with N-OAB who are refractory to medical management (Table 136.1) [40–42]. At 3 or 4 months following injection, bladder capacity had increased by 20–162%, detrusor pressure (important for preservation of upper tract function) had decreased by 22–61%,and total continence between CICs was achieved in 73–86.7% of patients [41]. Additionally, a reduction in the grade of vesicoureteral reflux was noted in another study, potentially as a result of decreasing bladder pressure [41].

Repeat injections

As the effects of BTX injection have been shown to last approximately 6–9 months, patients require repeat injections to continue to experience the therapeutic benefits. However, initially there were many concerns raised regarding the possibility that repeat injections would result in a blunted response over time due to antibody formation to the toxin. Several studies in N-OAB patients have evaluated the efficacy of repeat injections of BTX-A, with five to seven injections over a 6–8-year period, and have demonstrated that urodynamic and clinical improvements in QoL and decreased medication requirements after the first injection were maintained for a duration of 6–9 months after each subsequent application [33, 52–56]. Results in patients with I-OAB also demonstrated the same relief after a second BTX injection; some patients who had not shown a response following the first treatment actually showed a response to the second injection [57]. Additionally, it was postulated that repeat injections could result in fibrosis from repeated puncturing of the mucosa; however, this has not been shown to occur in several studies [58–60].

Adverse outcomes

Adverse outcomes associated with the injection of BTX include urinary retention requiring CIC, urinary tract infections, and muscle paralysis. These side effects led to early discontinuation of one randomized trial after the investigators noted greater than expected residual volumes and rates of urinary tract infections [35]. Generally, an increase in PVR can be expected following BTX injection; however, the threshold for initiation of CIC differs among the various studies, ranging from 100 to 200 mL [61]. The need to perform CIC may not be an issue for a patient with N-OAB who has likely had to perform CIC in the past; however, the need for *de novo* CIC may prove very bothersome in a patient who has never had to do so. Rates of CIC following BTX vary from 8% to 43%, and CIC usually needs to be performed for about 1–3 months until PVR decreases as the effects of the BTX wear off; of note, rates of CIC are significantly increased following repeat injections in patients who experienced retention with a prior injection [47, 62, 63]. Factors that have been shown to predict a need for *de novo* CIC are a projected isovolumetric detrusor pressure of less than 50 in women (sensitivity 0.83, specificity 0.7) and a bladder contractility index of less than 120 in men (sensitivity 0.7, specificity 0.79) [62]. Peripheral muscle weakness has also been noted to occur in rare instances, and has been associated with patients receiving a higher dose (1000 U) of Dysport [30, 33].

Technical considerations

BTX injection into the bladder wall was originally described by Schurch *et al.* using a rigid cystoscope and an endoscopic needle to inject 1 mL just beneath the detrusor mucosa at 20–30 sites sparing the trigone [23]. Later the "Dasgupta technique" was described using a flexible cystoscope; a sheath is passed through the working channel of the cystoscope to protect the scope during passage of a 27G needle and to stabilize the needle during injection [64]. Additionally, a minimally invasive sedation-free technique can be performed by instillation of 40 mL of 1% lidocaine into the bladder via a catheter 10 min prior to cystoscopy [65, 66]. Therefore, BTX injection can be performed in the operating room or office with either a rigid or flexible cystoscope, depending on surgeon preference. For treatment of patients with refractory OAB, we use a modified "Dasgupta" technique to inject the detrusor submucosa at 20 sites, sparing the trigone, with 200 U of Botox diluted to 20 mL at 1 mL/site (Figure 136.1). We do not use any systemic anesthesia but place a mixture of local anesthetics in the bladder 20 min prior to the intradetrusor injections.

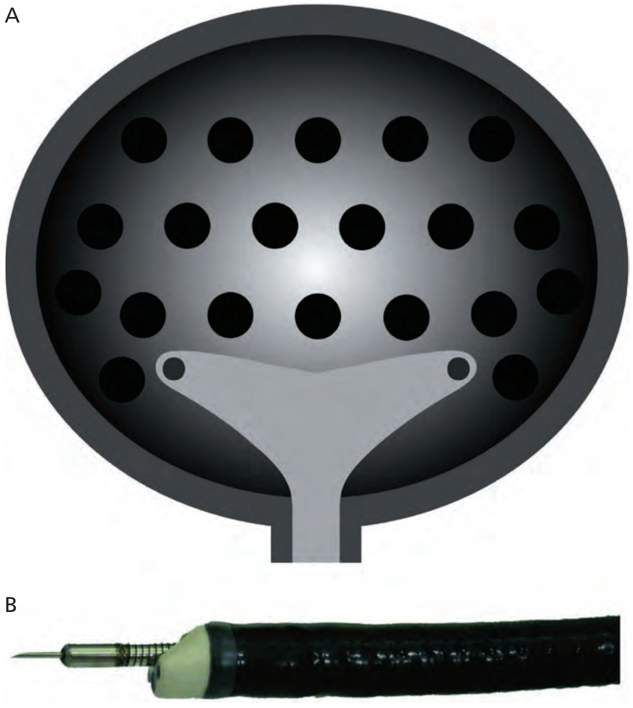

Figure 136.1 (A) Injection sites for botulinum toxin: 200 U of Botox diluted to 20 mL and injected into the detrusor submucosa at 20 sites with 1 mL/site, sparing the trigone. (B) Equipment used for modified "Dasgupta" technique of botulinum toxin: flexible cystoscope, sheath, and 27G injection needle.

Many of the initial studies advocated avoiding injection of the trigone as urologists felt it could lead to vesicoureteral reflux; however, this has not been shown to occur in two prospective studies [67, 68]. Injection of the trigone is not as effective in increasing capacity, but did have a greater effect on reducing urgency sensation in I-OAB [69]. Some studies have also explored injection of the urethra in patients at risk for urinary retention or with detrusor sphincter dyssynergia, with some positive preliminary results [70, 71].

The optimal dose of Botox or Dysport has not been determined. While higher doses of either drug are associated with improved urodynamic parameters, they are also associated with higher rates of urinary retention. Doses of Botox of 100, 150, 200, and 300 U have been diluted in 10–30 mL of preservative-free saline, yielding 10 U/mL, with 0.5–1 mL injected at 10–30 sites, and compared in various randomized controlled trials [28, 72, 73]. Dysport has been studied at doses of 500, 750, or 1000 U: 500 U resulted in too short a duration of action, while side effects with 1000 U were too great (there have been reports of temporary generalized weakness); therefore, many investigators have settled on using 750 U [30, 74].

Botox and Dysport have been compared head to head in only one open-label study with no obvious conclusion about which is the superior formulation [75].

Although the major focus of this chapter and of most trials has been BTX-A, BTX-B has also been investigated for use in OAB and found to have some efficacy but with a duration of only 6 weeks in limited trials [76].

The total cost of management of OAB and its consequences in the USA in 2000 has been estimated at over $US12 billion, with pharmaceutical costs constituting 10% of total costs [77]. Currently, the FDA has not approved the use of intradetrusor injection of BTX for the treatment of OAB, and thus most insurance companies do not cover such use. Therefore, most patients, unless they are involved in a clinical trial, have to pay for treatment themselves. Costs of treatment averaged £826 in the UK in 2008 (US$1 271.38) and BTX injection for treatment of OAB was determined to be cost-effective in two different analyses [78, 79].

Conclusions

A moderate percentage of patients with OAB, either from idiopathic or neurogenic causes, are refractory to anticholinergic medications and behavioral modalities, which are the first-line treatment. While patients with I-OAB may be treated with modalities such as sacral nerve stimulation (approved in the USA for this purpose), patients with N-OAB have limited alternatives, such as bladder augmentation. Endoscopic injection of BTX-A into the detrusor wall is gaining acceptance as a second-line therapy in these patients as studies have demonstrated clinical and urodynamic efficacy, resulting in fewer incontinent episodes, improved QoL, and increases in bladder capacity and decreases in maximum detrusor pressures. These beneficial results last approximately 6–9 months and injections can be repeated as necessary with no apparent tachyphylaxis. However, patients can experience increased residual volumes requiring CIC for 1–3 months until spontaneous voiding can resume, and also are at a higher risk for urinary tract infections. In general, doses of 100–200 U of Botox or 500 U of Dysport are injected for patients with I-OAB; 200–300 U of Botox and 750 U of Dysport for patients with N-OAB; and 10 U/kg (up to a maximum of 300 U) for the pediatric population. While surgeon preference determines whether injection of Botox is carried out with a rigid cystoscope under systemic sedation, many experienced investigators are using a flexible cystoscope and intravesical anesthesia in the office setting. Whether the use of Botox will become common in I-OAB remains unclear, but the primary deterrent would be the unpredictable need for CIC in this population. While Botox in the neurogenic population is effective and many of these patients already perform CIC, in a young patient who may require injections of Botox every 9–12 months, the advantages and disadvantages of reconstructive surgery (augmentation cystoplasty) need to be carefully considered.

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CHAPTER 137

STING Procedure for Reflux

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Introduction

The endoscopic treatment of vesicoureteral reflux (VUR) involves the injection of a bulking agent at the orifice of an incompetent ureter in order to create a suitable flap–valve mechanism to prevent the retrograde flow of urine during voiding. Many different types of bulking agents have been used in the history of endoscopic reflux therapy, although the perfect agent has been elusive. The ideal substance for endoscopic treatment of reflux should be easily injectable, nonimmunogenic, stable, and safe for human use [1].

Search for the ideal bulking agent

Matouschek was the first to describe the endoscopic treatment of VUR in 1981 when he detailed the injection of Teflon® polytetrafluoroethylene (PTFE) at the ureteral orifice to increase resistance to urine back flow [2]. Following the publication of excellent results using the subureteral PTFE (Teflon) injection (the STING technique) by O'Donnell and Pruri, the procedure received general acceptance in Europe, but was not widely used in the USA, where there was concern over implant migration [3]. The numerous reports of PTFE migration to remote areas such as the brain and lung following injection in the urethra and bladder neck sealed the fate of PTFE therapy [4, 5]. In addition to the risk of migration, there was concern over the development of granulomatous reaction around the PTFE, leading to possible calcification and making subsequent reimplant surgery difficult [6].

Once it was clear the future of the endoscopic treatment of reflux would not include PTFE, scientists searched for other agents to be used in the desirable technique. Silicone (Macroplastique; Urpoplasty Inc, Minneapolis, MN, USA) was a very effective agent when used with the STING procedure, correcting reflux in over 80% of ureters, with little morbidity. Unfortunately, silicone can cause a local foreign body reaction, and on the basis of the variable size of its particulates (35–540 μm), has a theoretical potential for migration risk. Also, the difficulty in injecting the viscous solution made the procedure less desirable. Finally, Macroplastique came to light at a time of great concern over systemic collagen disorders arising from silicone implants, and the material never achieved popular use [1, 7].

The next agent to be explored for the endoscopic therapy of reflux was glutaraldehyde-cross-linked bovine collagen (Contigen; C. R. Bard Inc, Murray Hill, NJ, USA). This substance has several characteristics that limited its widespread use for the STING procedure. First, it has the possibility of an allergic reaction, and therefore demands requisite allergy testing preinjection. Also, as has been noted in other areas of collagen injection (in cosmetic surgery, or the urethra for intrinsic sphincter incontinence), the substance has a limited staying power, and can show significant volume loss over time from the site of injection. Finally, long-term efficacy was not comparable to other, more durable agents [1, 7].

Calcium hydroxylapatite (Coaptite; Boston Scientific Inc, Natick, MA, USA) is a mixture of water and glycerin with 3% methylcellulose gel. It had commendable

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results in studies on patients with reflux requiring endoscopic correction, but had a higher single injection failure rate when compared to competing agents. The material is thought to be biocompatible and nonmutagenic, and currently is indicated only for female stress urinary incontinence secondary to intrinsic sphincter deficiency [1].

As research into tissue engineering expanded in the 1990s, one of the first areas investigated for human use involved the growth of chondrocytes for the treatment of VUR in children. Autologous chondrocytes were harvested from the auricular cartilage of patients and 6 weeks after their harvest and growth in culture, they were suspended in an alginate solution that included calcium chloride and calcium sulfate, which provided a scaffold for cartilage formation. The cells were then injected cystoscopically using the STING technique. The elastic cartilage tissue formed was able to correct VUR without any evidence of obstruction, and represented the first human application of cell-based tissue engineering technology for urologic applications [8].

However, the costs of the technique, as well as the need for a second harvesting procedure, limited the widespread use of the technology. In addition, variable degrees of cell growth appeared to occur, leading to inconsistent success rates [9].

Another novel material for use in the STING procedure was introduced in the late 1990s. Cross-linked dextranomer and hyaluronic acid (Deflux) had been used safely in the body for other indications for years, with no migration and long-term durability. Deflux has many of the characteristics of an ideal and effective bulking agent, as it is thin enough to allow needle injection, yet viscous enough to maintain its volume, is biocompatible, elicits minimal inflammation, and maintains its periureteral configuration over time [10].

Since the introduction of Deflux and its acceptance into widespread use, it has demonstrated excellent results and durability, and has become the agent of choice. As experience has grown with the use of Deflux, the techniques, methods, and circumstances of use have all evolved.

Technique

The traditional STING procedure involved the injection of bulking material just outside the ureteral orifice at the 6 o'clock position, elevating a mound with the compressed ureteral orifice located at the top of the hillock. Using the traditional STING technique, the success rates with Deflux injection, while variable, were acceptable, but certainly lagged behind those of surgical reimplantation. The Atlanta group pioneered a novel method, termed "HIT" and now "double HIT,", which has raised the success levels of Deflux injection above 90% [11, 12].

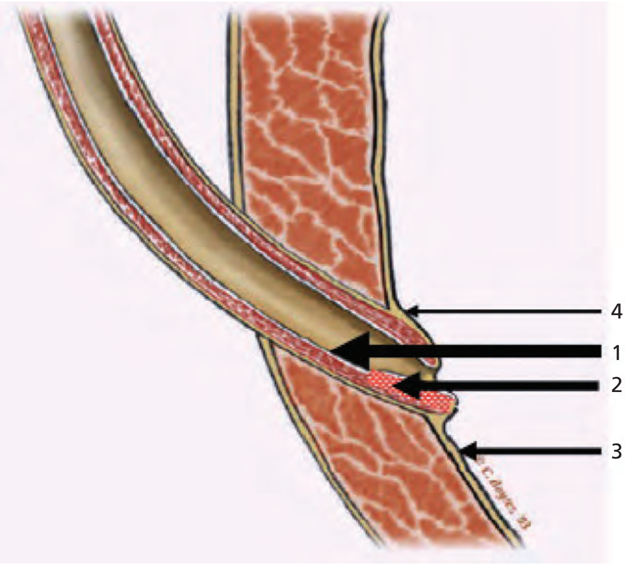


Figure 137.1 Locations of needle placement for the 1, intraureteric proximal technique (HIT); 2, intraureteric distal technique (double HIT); 3, traditional STING technique; and 4, superior tunnel (reproduced from Molitierno *et al.* [13], with permission).

In this method, the ureter is hydrodistended so that the needle may be placed inside the ureteral tunnel, a few millimeters within the orifice (see Video 137.1). This allows the first injection of the HIT technique to track bulking agent along the ureteral sheath, and more efficiently coapt the ureter (especially larger, dilated ureters). The second hit is similar to the traditional STING injection, but is slightly more cephalad, and coapts the ureteral orifice and elevates a mound of bulking material at the terminal ureter (see Video 134.2 for the complete double-HIT technique). This technique creates a "mountain range" of bulking material along the course of the ureter, as opposed to the original simple hillock (Figures 137.1 and 137.2) [13].

The double-HIT method has not only been employed for primary VUR (90% cure), but also for repeat endoscopic injections (90%), VUR associated with paraureteral diverticula (81%), complex cases such as post reimplantation (88%), neurogenic bladders (78%), duplication anomalies (80%), and in adults (88%). Several other studies have supported the use of Deflux in the setting of anatomic variants such as duplex systems as well [13–16].

The experience with the double-HIT technique was also important in identifying the need for sometimes large volumes of injectable material for cure. There is considered to be a 20% volume loss over time when using Deflux, so as a matter of technique it is important to use an adequate amount of material so that cure is ensured. Limiting the amount injected in an effort to

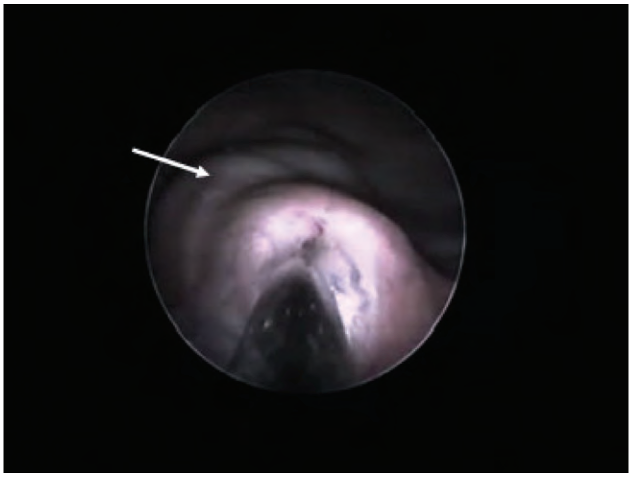


Figure 137.2 "Mountain range" mound (arrow) produced by the double-HIT injection technique (reproduced from Molitierno *et al.* [13], with permission).

limit costs often results in increased expenses later as failure rates are higher [17]. Also, failure is usually due to caudal migration of the bleb, so more proximal injection using the double-HIT method, as well as the larger volumes, has improved results [13].

The use of hydrodistention in these procedures also led to studies correlating the degree of ureteral distention with reflux. A grading system has been developed for ureteral dilation, which correlates well with grade of reflux. The hydrodistention grading system defines grades of reflux as: H0, no hydrodistention; H1, ureteral orifice open but tunnel not evident; H2, tunnel seen only, and H3, extravesical ureter visualized (Figure 137.3). In studies, VUR and dynamic hydrodistention classification grades correlate significantly ($P < .001$), and provide a reliable method of evaluating the presence or absence of VUR. These findings, combined with the studies demonstrating a lack of correlation of intraoperative cystogram and late cure, have allowed surgeons to do away with the postoperative cystogram (at the time of the injection), as lack of hydrodistention can confirm cure [11, 18].

Follow-up

Follow-up for STING procedures varies. As mentioned, it has been determined that a cystogram is not needed at the time of injection, as ureters that do not hydrodistend are considered cured. Cystography may, however, pick up contralateral unrecognized reflux, which may then be easily treated [19].

Traditionally, patients are observed for approximately 3 months on prophylactic antibiotics and then studied with renal bladder ultrasound and voiding cystourethrogram (VCUG) following injection therapy. In cases where the expected cure rate is high, the VCUG may be avoided and children do well. There has been some research into the appearance of injected bleb on postoperative ultrasound and cure rate. One study has demonstrated that while there is no difference in the volume of the visible Deflux on postoperative ultrasound in cures and failures, when a greater than expected volume of Deflux is retained (termed mega-implant), the cure rate is much higher than in cases with a less than expected volume remaining (micro-implants) or no visible implant [17]. The same study demonstrated durable implant size over 36 months postoperatively in these patients [17].

The bleb at the site of Deflux injection can persist long term, and this raises issues for future imaging and misinterpretations of the mass. Studies have demonstrated that the blebs can appear as calcifications on computed tomography (CT) scans and be mistaken for ureteral stones, and appear bright on T2-weighted images, but do not enhance on T1 scans [20–22]. It is important to note the history of intervention in these patients, so unnecessary medical interventions are not performed for these findings. The pathologic description of Deflux material has also been well described, so any tissue sent for pathologic evaluation in cases of reimplantation after injection therapy should be readily identifiable [23].

Long-term data regarding Deflux (approved for use in 2001) are not readily available, but some small studies have demonstrated durable results. Published results on the long-term efficacy of endoscopic use of Deflux for VUR have concluded that subureteral injection of Deflux for children with VUR is an effective and durable treatment option for VUR with a low complication rate. Other studies, however, have raised great concerns for the long-term efficacy of Deflux, as there may be a high documented rate of late recurrence. However, these patients with later failures had risk factors, such as dysfunctional elimination, which may have contributed to the poor results. For now it seems prudent to follow these children closely for several years until durable and reliable long-term data are available [24–26].

Role of the STING procedure

Typical of many areas in pediatric urology, the treatment of VUR is highly controversial. The opinions on STING therapy for reflux vary from religious opposition to overzealous support. The exact role for Deflux therapy remains to be defined, but it is clear that it is gaining a more prominent position in the armamentarium of the surgeon treating various forms of reflux. Studies have expanded its role from simple refluxing ureters, to more complex systems, such as duplicated ureters, ureters

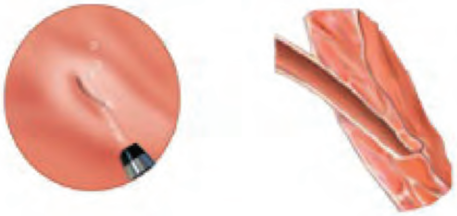
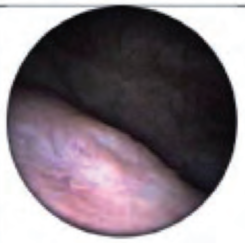
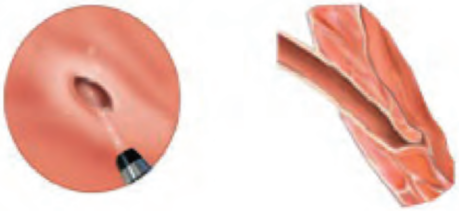
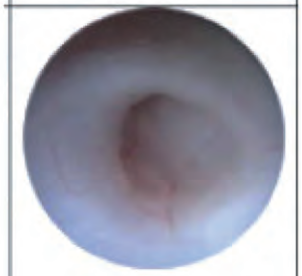
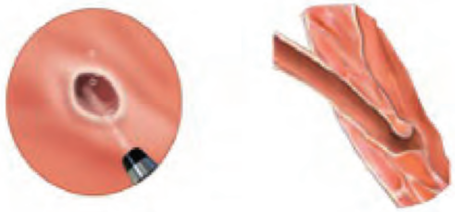
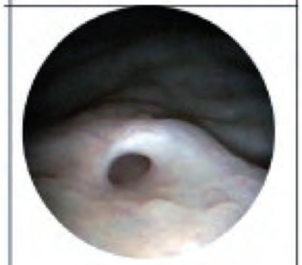
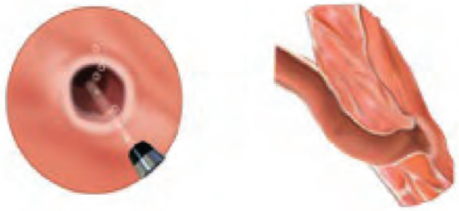
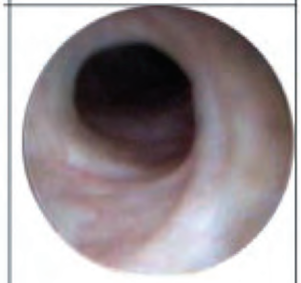
Hydrodistention Grade	Description	Cystoscopic appearance	Example
H0	No orifice distention evident		
H1	Orifice opens Intramural tunnel not evident		
H2	Orifice opens Intramural tunnel evident Extramural ureter not evident		
H3	Orifice opens Extramural ureter evident or ureter can accept cystoscope		

Figure 137.3 Hydrodistention grading system developed by Kirsch *et al.* (reproduced from Kirsch *et al.* [18], with permission).

associated with diverticula, transplant ureters, and even ureters in neurogenic bladders. The appeal of STING therapy to many is that the procedure poses minimal morbidity with the chance of great reward if a cure results. If cure is not achieved, the grade of reflux is often downgraded to a less clinically significant level, and repeat injections may also be preformed. Once STING has failed twice, all experts agree that any surgical intervention needed should then proceed to open reimplantation, and surgery following even repeat Deflux procedures is only slightly more difficult than virgin surgery. In summary, this procedure may offer a simple cure, while not burning any bridges [27].

There is a concern that Deflux injection, being a relatively simple procedure, will be overutilized to the detriment of patients. As with any technology or procedure, the clinician's judgment is crucial to the success of the methodology chosen, and judicious use of any technique is a must [28].

As with any new technology, some have attempted to push the envelope with mixed results. Some have used Deflux in combination with botulinum toxin A injection as a means of total endoscopic management of a noncompliant neurogenic bladder. These combined therapies were able to decrease bladder pressure and the rate of urinary tract infections (UTIs) [29].

The detractors of STING therapy point to studies expressing low cure rates per ureter, extolling that it is in the best interests of the patient to provide a one time, highly successful surgery. The proponents rely on the support of studies stating higher cure rates, and the "less is more" philosophy of surgical intervention. It seems that these differences are often philosophical, and depend on the personality, experiences, and training of the surgeon, and all the studies published have done little to sway adherents from either camp to the other side.

A unique benefit of the STING procedure is that it can easily be paired with a positionally instilled cystogram (PIC) as a simple procedure to diagnose and treat VUR. Studies have demonstrated that children with recurrent febrile UTIs with negative VCUG studies may have occult reflux (as VCUGs have a known false-negative rate), and these cases can be diagnosed and treated with PICs followed by Deflux injections. The PIC is performed by using cystoscopy with contrast running as the irrigation fluid and pointing the beak of the cystoscope at the ureteral orifice in a partially filled bladder. Fluoroscopic images of reflux are considered proof positive of occult reflux, and treatment with STING therapy is almost always the next option. Considering the relation of ureteral hydrodistention and reflux grade, it may be debatable as to whether contrast instillation is necessary in an obviously distended system (grade 3), but documentation of the pathology is always helpful in justifying the therapy [30, 31].

Another interesting area of research into the uses of the STING procedure for reflux therapy has been the push by proponents of the technique to use it as a first-line therapy for reflux. These authors point to the low patient compliance with prophylactic antibiotics, claiming that first-line injection therapy would be a more inexpensive, simpler option for families, with little morbidity. For example, Hensle *et al.* noted that only 17% of patients with VUR on prophylaxis are compliant and that 58% had a diagnosis of UTI within 1 year of treatment [32]. Elder *et al*. demonstrated that treatment with Deflux in children with reflux resulted in fewer UTIs than management with prophylactic antibiotics, and concluded that Deflux should be considered first-line therapy [33]. Koyle and Caldamone made a case that misuse of antibiotics has spread resistance, and thus should be replaced by first-line Deflux therapy in appropriate patients [34].

There is a general lack of controlled studies regarding prophylaxis, although efforts are underway to ameliorate this deficiency. The RIVUR study (Randomized Intervention in Children with Vesicoureteral Reflux) is designed to determine whether small doses of antibiotics can prevent recurrent UTIs and/or kidney damage, although recruitment has been slow. In general, compliance is low with antibiotic prophylaxis, but that does not mean that the therapy is ineffective or not worthwhile. When given appropriately, prophylaxis does prevent infections, and does not have a large impact on microbial resistance [35]. All parents should have all options discussed with them on visits with their child's pediatric urologists (from open surgery to prophylaxis), and prophylaxis remains standard first-line therapy. New innovations, including injection therapy, should be closely studied and offered in an unbiased fashion.

With the availability of minimally invasive techniques, such as extravesical ureteral reimplantation, mini-ureteroneocystostomy, and extravesical and intravesical laparoscopic and robot-assisted procedures, there has been a push by some surgeons to prove that traditional ureteral reimplantation can be performed with new techniques and technology in an outpatient setting, with comparable morbidity and higher cure rates than with endoscopic procedures. Some studies have also demonstrated decreased total cost with these procedures. It is clear that as minimally invasive surgical technology advances, there will be pressure on the endoscopic options of therapy to maintain high cure rates to compete with these increasingly inexpensive and benign procedures [36–38].

The choice of therapy for VUR remains controversial. The main goal of preventing renal scars and infection in these young children must be kept in mind, and we are fortunate to have a multitude of excellent options to choose from to achieve this goal. In the hands of a trained pediatric urologist, with close follow-up of their patients, all three options of antibiotic prophylaxis, STING therapy, and open surgery can be used wisely in an effort to maintain urologic health.

Dysfunctional elimination

It is our opinion that as the identification and treatment of dysfunctional elimination improves, the rates of resolution of refluxing ureters will also improve (as well as the success rates of STING procedures), obviating the need for open surgery in most children [39]. In fact, the Atlanta group currently reserves open surgery only for patients who fail injection therapy (two injections), have high-grade reflux or megaureters (that require tapering), and if this is the preference of the parents [13].

Results have been published showing that the treatment of dysfunctional elimination does not affect the success of endoscopic therapy of reflux, but the definition of dysfunctional voiding and the documentation of its successful treatment are not always well documented

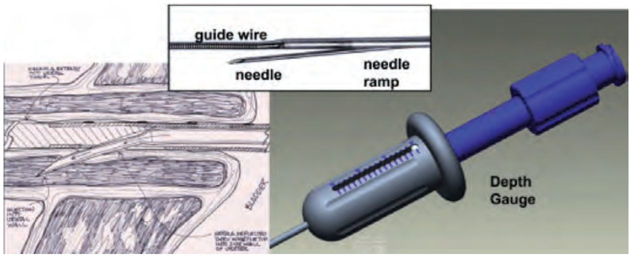


Figure 137.4 Cook Injekt VUR Injection needle. The device has a filiform tip with markings to help physicians achieve proper needle position and depth relative to the ureteral orifice for precise placement of the bulking agent (reproduced from Molitierno *et al.* [13], with permission).

or proven [13, 40]. Our center has unpublished data showing that the incidence and severity of dysfunctional elimination is widely underestimated, and that a focus on biofeedback and constipation therapy may greatly reduce the incidence and severity of reflux in children.

Conclusions

The introduction of Deflux into the realm of endoscopic reflux therapy has provided surgeons with an almost ideal bulking agent, and allowed for the expansion of the STING procedure. The techniques have improved, as well as the results, and endoscopic therapy has become a reasonable option for almost all children with reflux, and in some circumstances a good first option. As the treatment of dysfunctional elimination becomes more codified and widespread, the need for open surgery will likely wane, while the numbers of endoscopic cases will continue to expand. The growing experience among practicing urologists, standardization of techniques, and introduction of new tools that help the consistency and accuracy of needle placement (Figure 137.4) will help ensure reproducibly high success rates for endoscopic therapy in the future.

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CHAPTER 138

Minimally Invasive Therapy for Interstitial Cystitis/Painful Bladder Syndrome

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Introduction

Interstitial cystitis (IC), also known as painful bladder syndrome (PBS), is a common disorder of the urinary bladder affecting mostly young and middle-aged women; however, it has also been reported in men in whom it is often difficult to distinguish from chronic prostatitis. This clinical syndrome is a diagnosis of exclusion and no single treatment has yet been established to alleviate all symptoms. Increasing evidence links comorbid conditions to IC/PBS, allowing for investigation of potential pathologic pathways and application of novel therapies. This chapter will review IC/PBS with focus on minimally invasive treatment options.

Definition/nomenclature

IC/PBS is a disorder primarily manifest by bladder/pelvic pain and irritative voiding symptoms, such as urgency and/or frequency. Once considered a disease process related only to the bladder, it is becoming increasingly evident that the condition may associate with other pain syndromes and medical conditions affecting multiple organ systems [1]. The constellation of IC/PBS symptoms has been assigned different names to reflect its broad clinical spectrum, and this continues to evolve. The International Continence Society (ICS) prefers the term painful bladder syndrome (PBS), while the European Society for the Study of Interstitial Cystitis proposed the name "bladder pain syndrome."

Two different forms of IC/PBS have been described, and prognosis and treatment may vary depending upon the form detected. "Classical" disease is characterized by erythematous patches, termed Hunner's ulcers (or Hunner's patches), after Guy Hunner, the surgeon who first described these lesions. Hunner's ulcers occur in less than 10% of patients [2, 3]. Only cystoscopy can accurately determine if inflammatory disease is present, as only approximately 30% of these patients show abnormalities on urinalysis that would otherwise prompt a cystoscopic examination. "Nonclassical" disease is characterized by a normal cystoscopic examination in the face of typical symptoms and no evidence of any other pathology [4].

Epidemiology

Considering the difficulty of establishing an accepted definition, collected data have been difficult to interpret and this has led to variations in reported prevalence around the world. In a large study from Finland, the estimated prevalence in women was 230 per 100 000, and a study of urban females in Vienna, Austria gave an overall estimate of 306 per 100 000 women, with the highest prevalence (464 per 100 000) among middle-aged females (40–59 years old) [5, 6]. Similarly, a US population-based study found the prevalence to be 197 per 100 000 women and 41 per 100 000 men [7]. Screening and data collection based on symptoms rather than diagnosis show the prevalence to be much higher. A primary care office survey screening patients for symptoms of IC

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estimated the prevalence to be 12 600 per 100 00 women [8]. Studies by Parsons *et al*. suggest that IC is highly prevalent in young women and may affect as many as one in four [9, 10]. The female-to-male ratio is reported as approximately 10 : 1 [7, 11]. However, given the difficulty in distinguishing between IC/PBS and the chronic pelvic pain syndrome (CPPS) that affects men, the percentage of males with IC/PBS may be underestimated and the ratio is likely closer to 5 : 1 [12, 13].

Most patients with IC/PBS are adults, but the condition has been reported in children and young adults [14, 15]. The presence of childhood bladder problems, such as dysfunctional voiding or enuresis, is reported to be 10 times higher in IC/PBS patients versus the general population.

Data further suggest that IC/PBS has a negative effect on quality of life. IC/PBS often coexists with conditions such as depression, chronic pain, anxiety, and poor overall mental health [11].

Etiology

While a single cause of IC/PBS remains unknown, numerous pathologies have been documented. Increasing data suggest that IC/PBS may be a systemic disorder with bladder symptoms and pelvic pain being the main manifestation [16, 17]. Some evidence exists of a genetic predisposition to IC/PBS. Adult female first-degree relatives of patients with IC/PBS are reported to have a prevalence of IC/PBS 17 times that found in the general population [18]. Additionally, there is a greater concordance of IC/PBS among monozygotic than dizygotic twin pairs, strengthening the evidence for genetic susceptibility to IC/PBS [19].

An infectious etiology for IC/PBS has been proposed. Various pathogens, including bacteria, viruses and fungal agents, have been investigated, but even highly sensitive and specific molecular methods for identifying infectious agents by detection of DNA or RNA were unable to demonstrate any particular microorganism or virus responsible for the development of IC/PBS [20]. Another infection-related theory is that pathogens subvert host defense mechanisms, leading to frequent clinical or subclinical infections. This, in turn, may lead to the activation of neuroimmune pathways and the development of IC/PBS symptoms [21]. At this time no conclusive data exist to support an infectious etiology and it is unlikely that an active infection is involved.

Several other nonmutually exclusive theories that may help explain the pathogenesis of IC/PBS have been described in detail and are summarized in Table 138.1. Briefly, immune/neuroimmune mechanisms may have an important role in the pathogenesis, including excessive release of neurotransmitters, mast cell-mediated inflammation and morphologic changes in the nerves innervating the bladder. Several investigators have tried to establish the link between IC/PBS and autoimmune pathways; however, the pathways are not well defined and it is possible that the autoimmune phenomena described in IC/PBS patients are coincident [11].

Following the recognition of mast cells within the bladder wall, numerous studies were aimed at elucidating any possible role for them in the pathogenesis of IC/PBS. Mast cells play a primary role in allergic disorders and acute inflammatory response. These cells are also implicated in angiogenesis, wound healing, bone remodeling, arthrosclerosis, and reaction to neoplasms. Multiple components, such as endocrine, immune, and neurologic pathways, are suggested to contribute to the pathogenesis of IC/PBS and activated mast cells play a central role in the activation and signaling of these pathways, linking these cells to the disease process [22–24].

The bladder surface epithelium is lined by bladder surface mucin, a continuous layer of proteoglycans and

Table 138.1 Potential mechanisms involved in the pathogenesis of interstitial cystitis (adapted from Theoharides *et al*. [36]).

Mechanism	Pathophysiologic effect
Bladder lining abnormalities	Damage to the bladder protective glycosaminoglycan layer
Abnormalities of descending inhibitory pain pathways	Dysfunction in brain centers (or the pathways from these centers) that normally downregulate pain signaling in the spinal cord
Neurogenic inflammation	Increased bladder neuropeptide containing nerve endings juxtaposed to increased and activated mast cells, increased urine interleukin (IL)-6
Neurohormonal dysregulation	Dysfunction in the hypothalamic–pituitary–adrenal axis, including higher bladder expression of corticotropin-releasing hormone (CRH)
Decreased urothelial repair	Increased secretion of antiproliferative factor (APF) shown to inhibit urothelial cell growth *in vitro*
Comorbid conditions	Mechanism unknown; increased rate of psychiatric comorbid conditions, including depression, anxiety, post-traumatic stress, and somatization, as well as allergies, chronic fatigue syndrome, endometriosis, fibromyalgia, IBS, and IBD [13,25, 80–88]

glycosaminoglycans (GAGs). This layer (commonly called the "GAG" layer) is thought to provide both a permeability barrier to noxious solutes in the urine and a host defense against bacterial adherence. Injury or destruction of the protective layer leads to increased epithelial permeability and susceptibility to infection. The absence of this layer and its protective function can be duplicated by application of exogenous GAG. Increased mucosal permeability is nonspecific and can be a consequence of bladder inflammation, injury or chemical cystitis, and it may be part of the normal process of aging. Parsons and Hurst hypothesized the concept that IC/PBS in a subset of patients is the result of some defect in the epithelial permeability barrier of the bladder surface GAG [25]. Multiple investigators have demonstrated a link between increased mucosal permeability and GAG layer damage, but whether this represents a primary cause of IC/PBS or merely reflects a secondary event is unclear [26–28]. An argument against the "GAG theory" is that injury to this protective layer via fulguration of bladder lesions, bladder hydrodistention, or the intravesical administration of clorpactin or the organic solvent dimethyl sulfoxide (DMSO) may improve bladder symptoms. On the other hand, treatments aimed at "restoring" the GAG layer have a role in the treatment of IC/PBS and will be discussed later in the chapter.

Inflammation, especially if repeated or chronic, can alter tissue innervation, central pain processing mechanisms, and tissue response. Neuropeptides present in the spinal cord have an important role in the mediation of nociceptive input, which, under pathologic conditions such as inflammation can be altered, leading to functional consequences. Activation of pain fibers can trigger neurogenic inflammation through release of neuropeptides and subsequently increase vascular permeability. Furthermore, mast cell degranulation can be stimulated by neuropeptide mediators, leading in term to exacerbation of inflammation, injury, and increased epithelial permeability. Numerous studies also indicate increased sympathetic activity in patients with IC/PBS [29–31]. Neurogenic inflammation is compatible with the central role of mast cells and the leaky epithelium theory. Dysregulation of the pelvic floor, resulting in chronic pelvic pain, may be the result of central nervous system upregulation and augmented sensory processing. New treatment possibilities may arise from further investigation and better understanding of the neurobiology and its role in the pathogenesis of IC/PBS [11].

Investigation by Keay *et al*. into the role of certain cytotoxins in the epithelial damage seen in IC/PBS led to the discovery of the antiproliferative factor (APF) [32]. In further studies, the presence of this factor was found to be a sensitive and specific biomarker for IC/PBS. The presence of APF significantly decreases levels of heparin-binding epidermal growth factor-like growth factor (HB-EGF) and at the same time upregulates the levels of epidermal growth factor (EGF), which leads to inhibition of primary urothelial cell proliferation. Urine levels of APF, HB-EGF, and EGF reliably separate out IC/PBS patients from controls [33]. The presence of APF activity has been shown to differentiate between men with IC/PBS versus CPPS/chronic prostatitis [34]. These tests are not commercially available.

Signs/symptoms and diagnosis

IC/PBS is a clinical diagnosis of exclusion based upon chronic (3–6 month) pain or discomfort perceived to be bladder based. The pain usually varies with the degree of bladder distention; hence, urgency and frequency of urination are usually present in an attempt to minimize discomfort. Urinary tract infection and other potential treatable causes must be excluded. Median age of presentation in women is 40–45 years [35]. According to reports from the interstitial cystitis database, the most common baseline pain sites are lower abdominal pain (80%), urethral (74%), and lower back (65%). Most patients describe intermittent pain of moderate intensity and there have been reports of links between pain sites and urinary symptoms [35]. The pain often worsens with filling of the bladder and may be relieved by voiding [36]. Men compromise about 10–15% of IC patients. There is significant overlap in symptomatology when comparing IC/PBS and chronic nonbacterial prostatitis. Frequently associated findings in men are erectile dysfunction, painful ejaculation, and microhematuria. Urinary frequency is less commonly reported [12].

No reports point to IC/PBS as a potential premalignant condition; however, it is important to rule out bladder cancer, especially the presence of carcinoma *in situ* in patients aged over 40 years with a smoking history. Other rarer conditions, such as eosinophilic cystitis, malacoplakia, scleroderma, schistosomiasis, and detrusor endometriosis, must also be considered. In women, gynecologic problems, specifically endometriosis, can mimic the IC/PBS symptom complex and careful evaluation to rule out any correctable condition should be undertaken. Patients evaluated for IC/PBS may report urgency along with other symptoms and a diagnosis of overactive bladder (OAB) should be considered. Urgency felt by patients with IC/PBS is considered secondary to pain rather than the impeding loss of control typical for OAB [11]. A large-scale survey of individuals diagnosed with IC/PBS showed an unexplained association with other chronic disease and pain syndromes. Allergies, irritable bowel syndrome, and sensitive skin were the most common associated conditions [37]. Although not based on randomized trials, small observational studies suggest that high levels of stress tend to increase pain and urgency in patients with IC/PBS [38, 39].

Patients considered for a diagnosis of IC/PBS should have a careful evaluation, starting with assessment for increased daytime and night-time frequency, and suprapubic pain/pressure/discomfort related to bladder filling. In 1987, the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) developed a list of clinical criteria to better identify patients with IC and compare data collected from different geographic areas [40]. Due to the restrictive nature of the NIDDK criteria, use in clinical practice would likely miss an estimated 60% of patients and should be restricted to research only [41].

A thorough medical history should include the presence of allergies, gastrointestinal, gynecologic, autoimmune, and musculoskeletal disease. Symptoms can be evaluated using any of the validated questionnaires, all of which are designed to assess severity of symptoms rather than to serve as a diagnostic tool. Symptom scales available include the one-page O'Leary-Sant Symptom and Problem Index, the University of Wisconsin Symptom Instrument, and the Global Response Assessment (GRA). These scales can also be used to measure response to treatment and are valuable in clinical research.

A presumptive diagnosis can be made solely based upon the history and physical examination, and other testing to exclude other well-defined illnesses. Urinalysis and urine culture are part of a standard urologic evaluation for the IC/PBS patient. Further evaluations with urine cytology, special cultures (such as testing for acid-fast bacilli), office cystoscopy, urodynamics, and radiographic imaging are performed based upon the patient's clinical presentation and history.

Hydrodistention under anesthesia is still considered by many urologists to be the "gold standard" to aid in the diagnosis of IC/PBS. Glomerulations, submucosal petechiae, are frequently seen after the irrigant pressure is released (see Figure 138.3). The capacity of the bladder at 80–100 cmH_2O is measured (anesthetic bladder capacity) and is usually reduced in the IC/PBS patient (normal anesthetic bladder capacity, 800–1200 mL; in IC/PBS usually <800 mL). The procedure has fallen out of favor with many urologists due to its lack of sensitivity and specificity.

When Hunner's ulcers are seen on cystoscopy (Figure 138.1), biopsies should be taken from these lesions to exclude carcinoma *in situ*. Only cystoscopy can accurately determine if inflammatory disease is present, as only approximately 30% of these patients show abnormalities on urinalysis that would otherwise prompt a cystoscopic examination [4].

Intravesical administration of concentrated potassium chloride, known as the potassium sensitivity test, is still used by some physicians to distinguish the source of pain in women with chronic pelvic pain and possible IC/PBS. The test can be easily performed in the office setting, but may provoke pain and it has a low diagnostic value (75% sensitivity) [42]. Another office-based test is the "anesthetic challenge." It is especially useful in patients presenting to the office with active pelvic pain, and includes installation of an intravesical anesthetic. Although there is no documentation about sensitivity and specificity, this test is reasonable and can yield useful information about likelihood of bladder-based pain, especially in patients who have a positive response.

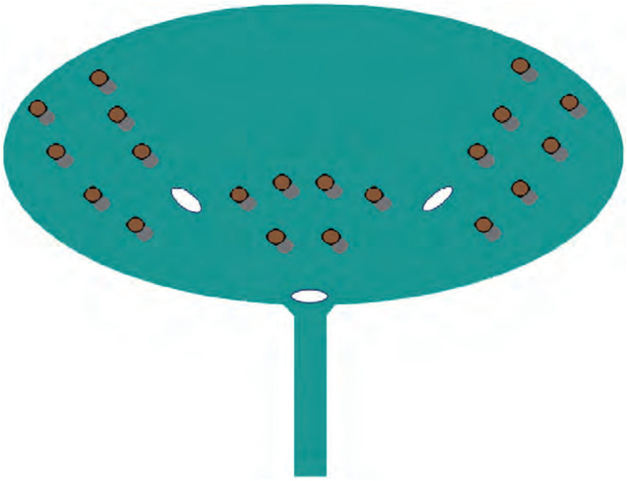

Figure 138.1 Location of injection sites for botulinum toxin (reproduced from Giannantoni *et al.* [67], with permission).

Management

One of the greatest challenges facing physicians and other healthcare providers is treating patients with IC/PBS. Even when urinary symptoms are addressed, many patients experience debilitating pelvic pain that is difficult to treat. Recognizing that the etiology of IC/PBS is likely multifactorial, patients are now often treated with multimodal therapy to address the different pain components. Lifestyle modifications, pharmacologic therapy, physical therapy, and surgical treatment options are available and often used in sequence or combination to offer patients the best symptom control possible [43].

Once diagnosed, patients are usually counseled and undergo a period of conservative management with careful assessment of the severity of symptoms. Patient education and empowerment are cornerstones of initial therapy. The patient should be reassured that although symptoms are bothersome, no life-threatening disease is present, and many therapies are available to control symptoms. In patients with predominant frequency rather than pain, behavioral–modification therapy can be helpful. Diary keeping, controlled fluid intake, and pelvic floor muscle retraining can be combined to increase voiding intervals [11]. Expert opinion suggests that maintaining a normal lifestyle and increasing the quality of life for patients with IC/PBS can be augmented by stress reduction, exercise, and warm tub baths; however, no randomized trials are available to support or prove it. Acupuncture has been used in patients with IC/PBS as well as other chronic pain syndromes. Limited evidence exists that it is more effective than placebo and overall results with acupuncture have failed to show efficacy [44, 45].

Dietary modification is another first-line treatment modality that is often used. Many patients report symptom exacerbation by specific foods, including spicy foods and beverages including coffee, soda, and alcohol. A recent questionnaire-based study suggested that approximately 90% of IC/PBS patients have food sensitivities [46].

Initiation of therapy often starts with oral agents, such as amitriptyline, pentosan polysulfate (PPS) sodium, and hydroxyzine [36]. Amitriptyline is a tricyclic agent with four major pharmacologic actions: (1) blocks active transport at presynaptic nerve endings, affecting reuptake of serotonin and norepinephrine; (2) central and peripheral anticholinergic actions; (3) antihistaminic activity; and (4) sedative activity. The success rate reported with amitriptyline is 40–60% but most studies are based on a small number of patients. A large multicenter randomized controlled trial by Foster *et al*. showed that amitriptyline together with behavioral modification is no better than placebo when given to naïve patients with IC/PBS. Subgroup analysis demonstrated that patients who achieved and tolerated daily doses of 50 mg or greater did have improvement in symptoms [47]. Notable side effects include weight gain, constipation, urinary retention, dry mouth, and palpitations.

PPS is the only Food and Drug Administration (FDA)-approved agent, and a recent review of randomized controlled clinical trials showed it was "modestly beneficial" [48]. The drug presumably works by replenishing the defective GAG bladder mucosal layer. It is a synthetic, sulfated polysaccharide similar to the heparin sulfate analog, one of the GAGs normally found on the bladder surface [49]. The drug has also been found to be a potent inhibitor of allergic and nonimmune mast cell stimulation [50]. Sant *et al.* conducted a pilot clinical trial to evaluate the safety and efficacy of PPS. No benefit was observed compared to placebo, and adverse effects were reported to be minor and included reversible alopecia, diarrhea, headache, and skin rash. Limitations of this study included a small number of patients secondary to slow recruitment and it was most likely "underpowered" [51]. A meta-analysis by Hwang *et al*. showed the drug to be more efficacious than placebo in the treatment of pain, urgency, and frequency associated with IC/PBS [52]. The duration of therapy appears to be more important than the dosage. In a randomized, double-blind study by Nickel *et al*., different dosages were compared and patients were assessed for improvement of symptoms over 32 weeks. Patients showed similar improvement at dosages ranging from 300 to 900 mg and the overall response rate at 32 weeks was 50% [53].

Histamine H1 (hydroxyzine) and H2 (cimetidine) antagonists have shown some therapeutic effect in the treatment of IC/PBS patients. H1 receptor blockers can inhibit neuronal activation of mast cells and suppress degranulation. Evidence for the efficacy of hydroxyzine is limited and the maximum benefit demonstrated was a 40% reduction in symptoms [54]. Other data suggest no significant change in symptoms over placebo [51]. Cimetidine was developed as an oral treatment for peptic ulcer disease in the 1970s. Initial pilot trials showed efficacy of this agent in IC/PBS, and a subsequent study by Seshadri *et al*. supported these findings, reporting overall symptomatic relief in 66% of patients with IC/PBS [55]. The agent was also evaluated in a randomized trial in which patients taking cimetidine had a decrease in suprapubic pain and nocturia [56]. Limitations of this trial included a small sample size (n = 36), as well as a lack of qualitative change in the GAG layer or basement membrane of patients treated with cimetidine upon histologic evaluation of the bladder mucosa .

Minimally invasive procedures

Intravesical agents

The installation of intravesical agents provides a nonsurgical option for patients who fail conservative management, including oral medications, and may be considered one form of minimally invasive intervention. Treatment can be primary or in combination with other therapies. Several different agents are available, including DMSO, heparinoids, PPS, Bacillus Calmette–Guerin (BCG), clorpactin and, anesthetic agents. Some of the drugs are used in combination "cocktails."

DMSO, a lignin derivative, received FDA approval in 1978 for the treatment of IC/PBS. Its pharmacologic properties, including anti-inflammatory, analgesic, and muscle relaxant, make it a useful agent for the treatment of IC/PBS [57, 58]. Initially, the agent was used as a topical agent without success. It is now administered intravesically either as a single agent or as part of the DMSO "cocktail." Upon initial installation, patients may experience a flare-up of pain and irritative voiding symptoms, and typically report improvement after the third or fourth installation. Reported response rates range from 50% to 90% [58, 59]. A combination of DMSO with a mixture containing agents such as heparin sodium, a steroid, an antibiotic, and sodium bicarbonate is used for some patients who fail single-agent therapy. However, only data from case reports suggest better patient tolerance and clinical improvement [60]. Side effects from DMSO other than the initial pain flare are reported and include garlic-like odor and taste, which is usually self-limiting. The drug is not recommended for use during pregnancy [58].

Some evidence exists that dysregulation of the immune system with an imbalance of T1 and T2 helper cells may have a role in the pathophysiology of IC/PBS. Small pilot studies have shown that patients with IC/PBS may benefit from intravesical BCG. The attenuated live agent stimulates T1 helper cells, leading to an increase in cytokine release. However, a randomized controlled trial could not show significant response rates when compared to placebo (21% vs 12%, $P = .06$) [61].

PPS, when used as an oral agent, achieves a low bladder concentration, resulting in a long lag time (3–6 months) before clinical improvement can be observed [62]. Davis *et al.* examined the agent's safety and efficacy in a randomized trial comparing oral therapy to a combination of oral and intravesical PPS [63]. Patients who received the combined regimen had a two-fold reduction in the severity of IC/PBS symptoms compared to those receiving oral therapy only ($P = .04$). Overall quality of life was also significantly improved, making combination therapy a treatment option for patients with moderate and severe IC/PBS. The incidence of adverse advents was comparable in both groups

Intravesical anesthetic agents may have a role in treating patients with IC/PBS. Local anesthetics are weak bases and absorption is limited in the human bladder. Henry *et al*. showed that alkalinization of urine in the bladder provides safe and predictable lidocaine absorption and enhanced anesthetic action, leading to decreased pain scores in patients with IC/PBS [64]. Deep local bladder mucosal anesthesia could potentially be used during bladder hydrodistention and possibly the excision or fulguration of small bladder lesions without the need for sedation. The effect of intravesical alkalinized lidocaine (PSD597) has recently been assessed in a randomized trial [65]. The study included 102 patients randomized from 19 centers, all with a diagnosis of IC/PBS. Preliminary results showed the agent to be effective, providing short-term amelioration of symptoms in most patients. The effects lasted beyond the treatment period and no significant adverse effects were noted

In addition to diagnostic cystoscopy, minimally invasive procedures used to treat IC/PBS are hydrodistention, injection of intravesical botulinum toxin (BTX), transurethral resection, coagulation of inflammatory lesions, and laser ablation.

Intravesical injection of BTX is one of the more recently introduced procedures, usually requiring rigid cystoscopy and injection of the bladder mucosa. BTX-A is used to treat muscle overactivity and spasticity. BTX-A is produced from different strains of the bacterium *Clostridium botulinum* and it has been approved by the FDA for the treatment of strabismus and facial dystonias. Multiple unlabeled indications promoted and supported by mounting literature include treatment of focal dystonias, achalasia, and cosmetic correction of wrinkles. Additionally, many different pain disorders have been treated (not FDA approved) with BTX-A, including those related to muscle hyperactivity (chronic pelvic pain, dystonia, myofascial pain, tension headache), as well as pain resulting from neurovascular disorders and spinal cord pathology. BTX is currently undergoing regulatory evaluation for urologic disorders (OAB, benign prostatic hyperplasia, and IC) and is to date not FDA approved for urologic use [66].

Data are accumulating to provide clinical evidence for the efficacy and safety of BTX for the treatment of IC [67, 68]. Giannantoni *et al*. showed that intravesical injection is effective for the short-term management of refractory painful bladder syndrome [67]. Patients received 200 U of BTX-A diluted in 20 mL of 0.9% sodium, using a rigid cystoscope and a flexible needle. A total of 10 U were given per injection site (Figure 138.2) and injections were administered to the lateral

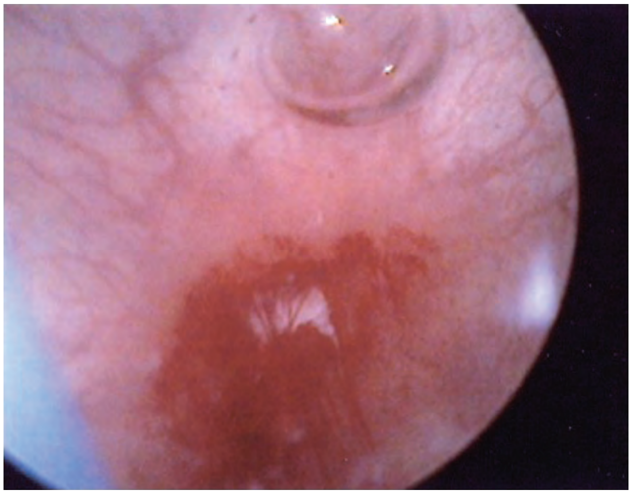

Figure 138.2 Hunner's ulcer. These are almost always extratrigonal. They tend to bleed and tear easily with even small amounts of bladder filling. In this setting, hydrodistention would be unwise, as it would likely lead to bladder perforation.

bladder walls and the trigone submucosa. The beneficial effect progressively decreased over a few months and a repeat treatment course was required to achieve lasting symptom control. Patients reported significant improvement in daytime and night-time frequency, and improved bladder capacity was noted on follow-up cystometry. Pain recurred eventually in all patients and nine of 15 experienced short-term impaired detrusor contractility necessitating clean intermittent catheterization (CIC). Smith and Chancellor *et al*. reported on successful use of BTX for patients with IC [69]. The injections, however, were limited to the submucosa of the trigone and floor of the bladder. BTX treatment was given after hydrodistention during the first injection and together with protamine for better absorption at 6 months. All patients returned home the same day, catheterization was not necessary, and no patient experienced urinary retention or bladder hypocontractility. Overall 71% of patients had significant improvement in the cystitis symptom index score.

Complications such as urinary retention necessitating an indwelling Foley catheter or detrusor hypocontractility subjecting patients to temporary CIC are the most disconcerting features of this procedure and should be discussed with the patient. Limiting injections to the bladder floor and the trigone decreases the chance of diffuse chemodenervation of efferent nerves [69, 70], and possibly the risk of incomplete bladder emptying and urinary retention, which have been noted in trials where the lateral bladder wall was injected as well [67, 71]. Myofascial dysfunction associated with chronic pelvic pain is observed in up to 70% of patients with IC.

Injection of the pelvic floor with BTX can be part of a multidisciplinary approach when treating IC patients and may achieve better pain control than injection of the bladder alone [72].

Endoscopic procedures

Hydrodistention is often used with diagnostic cystoscopy during the initial evaluation but it can also be used for therapy in select patients. The procedure is usually performed under general or regional anesthesia. Glycine is the irrigant of choice and distention of the bladder is performed under direct cystoscopic vision to avoid overdistention and mucosal tearing. Distention is limited to short periods of time, typically 2–5 min at a pressure of 80–100 cmH_2O. Submucosal hemorrhage (glomerulations) is often seen after hydrodistention and typically resolves (Figure 138.3). In patients with Hunner's ulcer, a biopsy should be done to rule out the presence of malignancy and fulguration of ulcers should be performed. Hydrodistention should not be performed in these patients, to avoid profuse hemorrhage and possible bladder perforation. All biopsy and fulguration sites, and mucosal tear locations should be noted to avoid confusion of these lesions on future cystoscopic evaluation. Finally, instillation of 20–30 mL of a short-acting anesthetic agent, i.e. 1% lidocaine, may be helpful for patients undergoing hydrodistention to allow for faster recovery and decreased pain following the procedure.

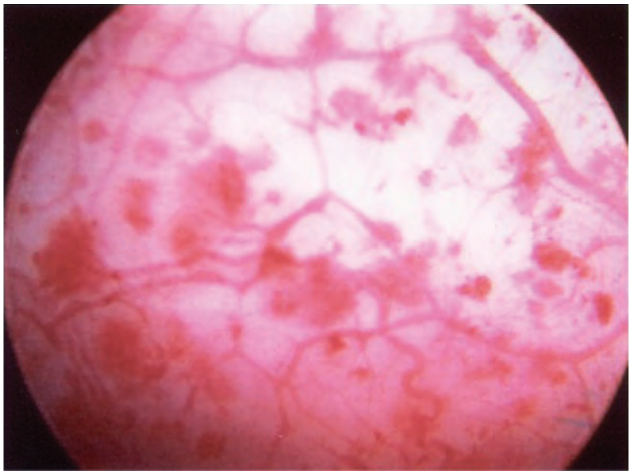

Figure 138.3 Glomerulations: submucosal hemorrhages typically seen in the interstitial cystitis/painful bladder syndrome patient after hydrodistention.

Reduction of symptoms ranges from 30% to 56% [73, 74]. Bladder distention was found to significantly reduce urine APF and HB-EGF toward normal.

The overall mechanism of symptom relief after hydrodistention is, however, still unknown [74], but theories include the increased elaboration of bladder surface mucin post hydrodistention or that hydrodistention actually causes a temporary nerve injury, resulting in some sensory impairment.

The procedure is considered safe; however, complications such as hematuria, bladder perforation, and bladder necrosis have been reported. Bladder perforation can usually be managed conservatively with catheter drainage. Vesical necrosis is a rare but serious complication of hydrodistention [75, 76].

For patients with severe IC/PBS and small bladder capacity, intravesical installation of hyaluronic acid can prolong the effect of bladder hydrodistention. The number of mean voids per day and bladder capacity were significantly improved for up to 9 month in patients receiving hyaluronic acid compared to treatment with hydrodistention only or hydrodistention with installation of heparin [77]. Similarly, intravesical injection of BTX at the time of hydrodistention has been found to reduce bladder pain. Liu *et al*. treated patients with 100–200 U of intravesically injected BTX followed by hydrodistention [68]. Treatment was considered successful if patients reported an improved quality-of-life

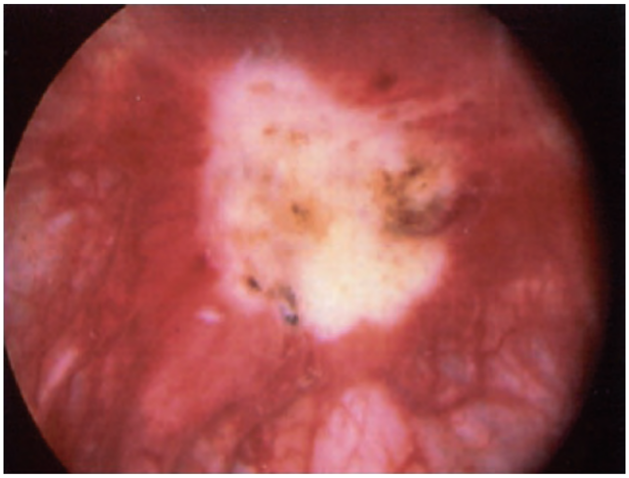

Figure 138.4 Hunner's ulcer after fulguration. Note the surrounding intense inflammatory reaction that develops rapidly after the applied energy. This is typically seen during the course of the ablative procedure.

index, complete resolution of bladder pain, and absence of voiding dysfunction. Partial response was recorded for patients with improved quality-of-life index, reduced pain (reduction of >2 points on the pain scale), and a greater than 25% reduction in urinary frequency. Patients reported symptomatic improvement at 3 month and the overall response rate was found to be 74%.

Classic or ulcerative IC/PBS affects about 5–10% of all patients with the disease and this subgroup may be amendable to endoscopic resection or fulguration of these lesions (Figure 138.4). In a retrospective analysis of 103 patients with classic IC/PBS, a total of 259 transurethral resections (TURs) of visible lesions were performed [78]. Ninety-two patients reported improvement of symptoms and in 40% of these relief lasted beyond 3 years.

Patients undergoing multiple procedures are at risk for bladder contracture and reduction of bladder compliance. Laser ablation can offer an alternative to TUR but comparison trials are lacking. Rofeim *et al.* conducted a prospective study investigating the use of the neodymium (Nd):YAG laser for IC [79]. A total of 24 patients were enrolled, treated, and prospectively followed up for 23 months. Low-energy (10–15 W) settings were used to ablate visible lesions in each patient. Response to treatment was noted 2–3 days after treatment. Patients reported a significant decrease in pain, frequency, and urgency. Fifty percent of patients needed only one treatment and had a mean response duration of 19 months. Retreatment is necessary in some patients and the treatment overall is not curative since ulcers recur. Possible benefits of laser ablation over electrocautery include less tissue damage to sounding bladder mucosa and hence less scarring. In the aforementioned trials, no complications developed; however, potential risks include bladder perforation, and bowel injury from forward scatter of the laser. These injuries may go undetected at the time of the procedure and postoperative assessment should include careful abdominal examination and electrolyte monitoring.

Conclusions

The diagnosis and management of IC/PBS remains challenging and the complexity of the disorder is only slowly being unraveled. No curative treatment has been established and effective treatment options are highly variable, depending on the individual patient. With increasing awareness and accumulation of basic and clinical research, future more effective treatment options may be discovered.

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CHAPTER 139

Incision: Endoscopic Management of Urethral Stenoses

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Introduction

Endoscopic management of anterior urethral strictures and posterior urethral stenoses takes many forms. Urethral dilation and incision with a cold knife or laser urethrotomy are techniques familiar to all practicing urologists. The use of and indications for urethral stents are sometimes misunderstood. While these procedures have their role in the treatment of urethral disorders, their use should be predicated upon a thorough understanding of urethral anatomy, etiology of disease, and goals of treatment.

Herein, we review urethral anatomy with special attention to the difference in stenotic processes that occur in each segment. The types of available endoscopic techniques are discussed and outcomes in each selected process are reviewed. A stepwise approach to evaluating patients with urethral strictures/stenosis is suggested so that the practitioner can gain an adequate understanding of the disease process prior to initiating treatment.

It is imperative that, prior to undertaking a course of treatment, the differences in urethral processes and expected outcomes for endoscopic treatment techniques are understood. Both practitioner and patient should agree upon the expected outcomes of intervention prior to treatment. In only a select few processes will endoscopic management be expected to be durably successful and as such, open urethral reconstruction remains the gold standard for many conditions where the patient's goals are cure of the process.

Urethral anatomy

An understanding of the anatomic relationship of the urethra and investing corpus spongiosum is imperative for the urologist performing endoscopic surgery on the urethra.

The corpus spongiosum is the third erectile body of the penis which lies in the ventral groove between the two corpora cavernosa (Figure 139.1). It is surrounded by a tunica albuginea, which is thinner than the tunica albuginea of the corpora cavernosa. The urethra transverses the length of the penis within the corpus spongiosum, and at the distal end the erectile tissue expands to form the glans penis. The bulbous urethra is eccentrically placed in relation to the corpus spongiosum and is much closer to the dorsum of the penile structures. Distally, the penile urethra is more centrally placed within the corpus spongiosum. The meatus is slit-like in configuration with a vertical axis and is on the ventral aspect of the tip of the glans penis (Figure 139.2).

At the International Conferences of Urologic Disease (ICVD) at both Stockholm and Marrakesh the consensus opinion was to subdivide the urethra into seven separate distinct areas (Figure 139.3):

1. The meatus represents the interface between the epithelium of the glans penis and the urethral epithelium. Normally its axis is vertical and calibrates in some individuals up to 30F.

2. The fossa navicularis, contained within the spongy erectile tissue of the glans penis terminates at the meatus.

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This portion of the urethra is lined with stratified squamous epithelium.

3. The penile or pendulous urethra lies distal to the investment of the ischiocavernosus musculature but is invested by the corpus spongiosum. This section of the urethra maintains a constant lumen size roughly centered in the corpus spongiosum. It is lined with simple squamous epithelium.

4. The bulbous urethra is covered by the midline fusion of the ischiocavernosus musculature and is invested by the bulbospongiosus of the corpus spongiosum. It becomes larger and lies closer to the dorsal aspect of the corpus spongiosum, exiting from its dorsal surface before the posterior attachment of the bulbospongiosus to the perineal body. The bulbous urethra is lined

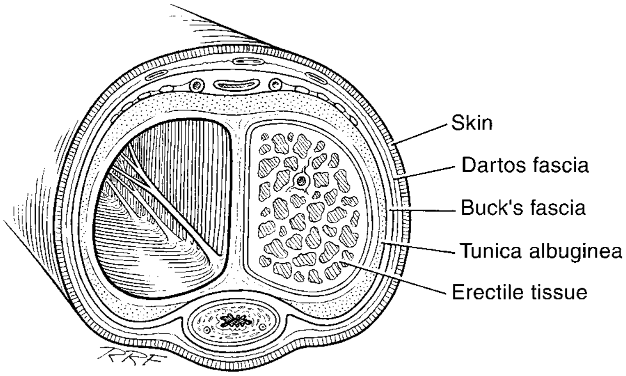

Figure 139.1 Anatomy of the penis. The fibers of the septum are attached to the inner layer of the tunica albuginea of the corpora cavernosa along the dorsal and ventral midlines.

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Figure 139.2 Cross-sections of the anterior urethra. (A) Bulbous urethra. The urethra is eccentrically placed in the corpus spongiosum. Proximally, the corpora cavernosa have split into individual crura, with the urethra lying against the triangular ligament. (B) In the shaft of the penis, the urethra is more centrally placed in relation to the corpus spongiosum, and the corpora cavernosa are intimately fused, separated only by septal fibers. (C) At the coronal margin, the urethra remains relatively centrally placed, and the corpora cavernosa are fused, again separated by septal fibers. The spongy tissue of the corpus spongiosum has become incorporated as the deep tissues of the glans. (D) The fossa navicularis widens somewhat in caliber and is totally surrounded by the spongy erectile tissue of the glans penis. The urethra here is relatively ventrally placed in relation to the body of the corpus spongiosum (reproduced from Jordan, G.H. Complications of interventional techniques of urethral stricture disease: Direct visual internal urethrotomy, stents and laser. In: Carson, C., ed. *Topics in Clinical Urology: Complications of Interventional Techniques*. New York, Igaku-Shoin, 1996, pp. 86–94, with permission).

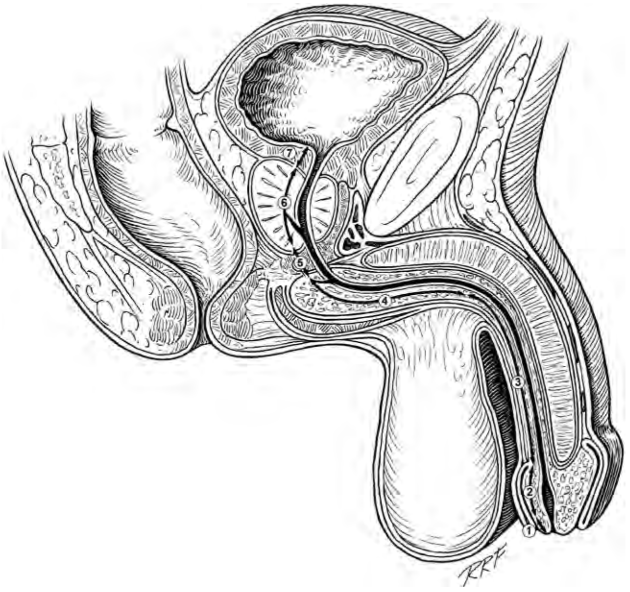

Figure 139.3 Sagittal section of the pelvis. The urethra is subdivided into the following sections: 1, meatus; 2, fossa navicularis; 3, pendulous or penile urethra; 4, bulbous urethra; 5, membranous urethra; 6, prostatic urethra; and 7, bladder neck. By common usage, the divisions of the meatus, fossa navicularis, pendulous urethra, and bulbous urethra compose the anterior urethra; and the divisions of the membranous urethra, prostatic urethra, and bladder neck compose the posterior urethra (modified from Devine, C.J. Jr, Angermeier, K.W. Anatomy of the penis and male perineum. *AUA Update Ser* 1994;8:11).

distally with squamous epithelium that gradually changes to the transitional epithelium found in the membranous urethra as it swings upward [1].

5. The membranous urethra is the portion that traverses the perineal pouch and is surrounded by the external urethral sphincter. This segment of the urethra is unattached to fixed structures and has the distinction of being the only portion of the male urethra that is not invested by another structure. It is lined with a delicate transitional epithelium.

6. The prostatic urethra, in common use, is the portion of the urethra that lies proximal to the membranous urethra and is mostly surrounded by the prostatic stromal and glandular tissue. Its epithelium is continuous with that of the trigone and bladder.

7. The bladder neck is the location of the bladder neck musculature, variably surrounded by intravesical protrusion of the prostate. Its epithelium is also contiguous with that of the trigone and bladder.

Urethral stricture disease

The term urethral stricture refers to anterior urethral disease, a scarring process involving the spongy erectile tissue of the corpus spongiosum, also referred to as spongiofibrosis (Figure 139.4). Under the urethral epithelium lies the spongy erectile tissue of the corpus spongiosum and in some cases, scarring can extend through the tissues of the corpus spongiosum and into adjacent tissues. As the scar contracts, it reduces the diameter of the urethral lumen. The normal urethra measures approximately 30F and its diameter is approximatly10 mm. The calculated luminal area is approximately 78 mm^2. If scarring has resulted in a urethra that measures 15F, the lumen is only 55 mm^2, a 29% reduction. Scar contraction caused by anterior urethral stricture disease can be markedly asymptomatic early in the process, but as the scarring process and contracture continue and the urethral lumen is further reduced, marked voiding symptoms can develop. This process may occur anywhere within the anterior urethra.

Posterior urethral "strictures" are, in fact, not referred to as strictures at all. By consensus of the ICUD conferences, the term stricture is limited to the anterior urethra; while distraction defects are a subcategory of those processes of the membranous urethra associated with pelvic fracture. Other narrowing of the posterior urethra, urethral contractures, or stenosis [2, 3] are processes that do not involve spongiofibrosis and are thus referred to as stenoses rather than strictures. As with anterior urethral strictures, posterior urethral stenosis is an obliterative process that has resulted in fibrosis and luminal narrowing. This process has often been initiated by a distraction injury, whether due to trauma or surgical manipulation. Although in some cases these stenoses can be lengthy, the actual process involving the tissues of the urethra is usually well confined. Conditions that result in posterior urethral stenosis include membranous urethral stenosis, prostatic urethral stenosis, bladder neck contracture, vesicourethral distraction, and posterior urethral distraction defects.

Etiology

Any process that injures the urethral epithelium and/or the underlying corpus spongiosum to the point that healing results in a scar causes a urethral stricture or stenosis. Anterior urethral strictures most commonly result from trauma, infection, inflammatory conditions or urethral manipulation. In many cases, the inciting event goes unrecognized by the patient until they present with obstructive voiding symptoms.

Traumatic injuries such as straddle injuries are a common example. Penetrating injuries, such as gunshot or stab wounds, may be appropriately treated initially and still lead to the development of delayed stricture disease. Iatrogenic trauma is a known etiology of urethral strictures, but with the development of smaller scopes and the recognition of the importance of careful technique, fewer of these cases are now being seen.

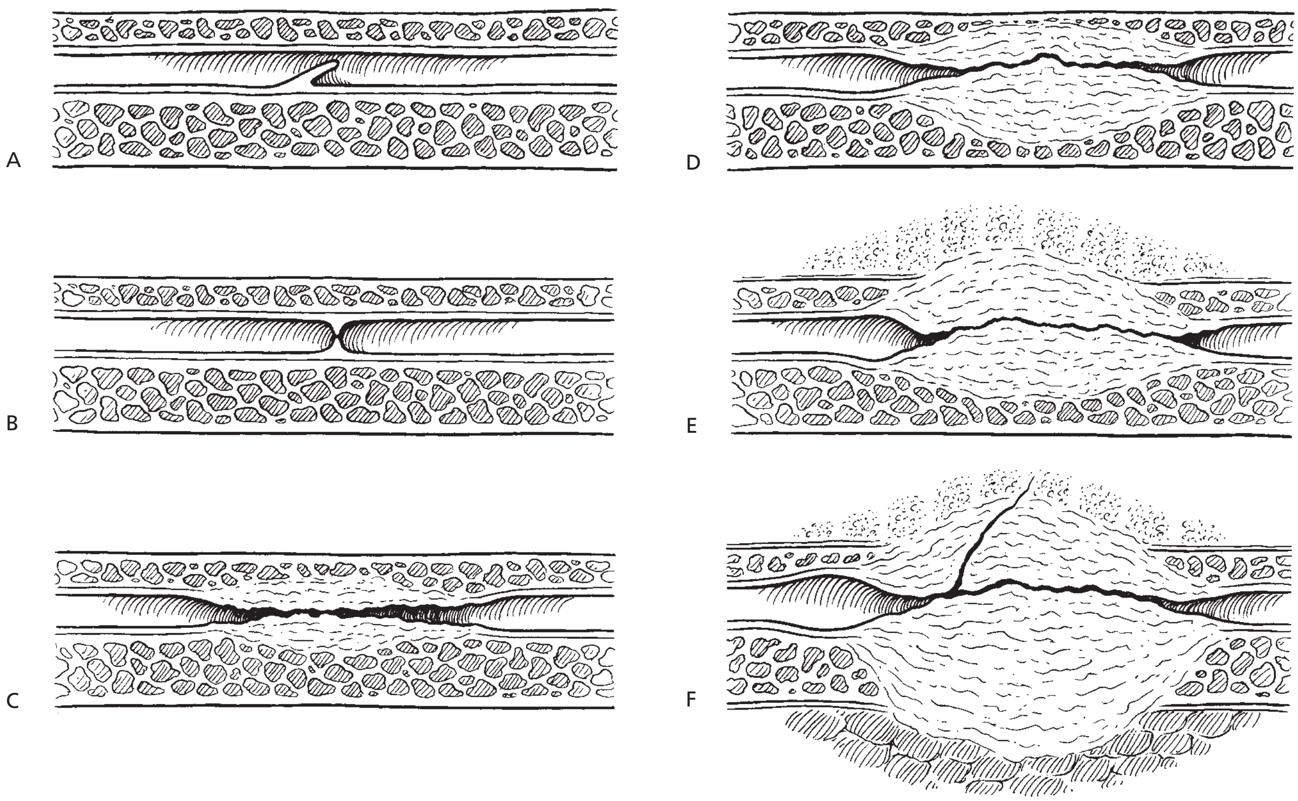

Figure 139.4 Anatomy of anterior urethral strictures includes, in most cases, underlying spongiofibrosis. (A) Mucosal fold;
(B) iris constriction; (C) full-thickness involvement with minimal fibrosis in the spongy tissue; (D) full-thickness spongiofibrosis; (E) inflammation and fibrosis involving tissues outside the corpus spongiosum; (F) complex stricture complicated by a fistula (reproduced from Jordan, G.H. Management of anterior urethral stricture disease. *Probl Urol* 1987;1:199–225, with permission).

The inflammatory dermatosis lichen sclerosus is a commonly seen disease process in patients with anterior urethral strictures. This condition behaves much differently from traumatic strictures, recurring quite readily, and thus requires special consideration when contemplating treatment options. Typically, the initial presentation is that of meatal stenosis associated with skin inflammation of the glans penis and prepuce. The inflammation then progresses proximally, perhaps due to distal obstruction, high pressure voiding, and subsequent microextravasation of urine into the corpus spongiosum and glands of Littre.

Infectious strictures associated with gonorrhea, which were commonly seen in the past, are now much less common. With the advent of more effective antibiotics and widely available medical care, gonococcal urethritis today rarely progresses to urethral stricture disease. As we understand the processes currently, nonspecific urethritis either due to Chlamydia or other organisms does not lead to urethral strictures.

The condition of idiopathic urethrorrhagia has in the past been felt to be related to urethral stricture because children were endoscoped for diagnosis. In years past, before the minification of endoscopes, it was felt that those stricture were iatrogenic. However, now there is accumulating evidence that the entity itself can cause proximal bulbous urethral stricture disease [4].

Finally, there are the so-called congenital strictures. These strictures occur in infants and young children, are short in length, noninflammatory, and not associated with potential for traumatic etiology. They are the rarest of all strictures.

Posterior urethral stenoses and anterior urethral strictures have many similar causes, although there are also several etiologies specific to the posterior urethra. Membranous strictures may result from urethral manipulation or radiation. Larger French resectoscopes, such as are used for transurethral resection (TUR) procedures, may cause tearing of the membranous urethra as it departs the corpus spongiosum. Brachytherapy seeds placed distal to the apex of the prostate can lead to radiation damage to this portion of the urethra as well. Prostatic urethral stenosis is rarely encountered, although when seen it may result from iatrogenic endoscopic manipulation of the prostate or radiotherapy. Bladder neck stenosis is seen commonly after TUR or radical prostatectomy. It is usually manifest as a short-length stenosis of varying caliber at the junction of the urethra and bladder. In some instances, endoscopic procedures for prostatic enlargement (whether traditional TUR or laser prostatectomy) are performed when there is an unrecognized underlying element of voiding dysfunction. In these cases, the symptoms that prompted treatment will certainly recur. Bladder neck stenosis typically responds well to endoscopic management, by gentle dilation or incision using cold knife, electrocautery or laser techniques. A more severe form of bladder neck stenosis termed vesicourethral distraction stenosis can be a devastating consequence of radical prostatectomy. It occurs when the vesicourethral anastomosis is disrupted and leads to a longer defect that is quite resistant to endoscopic treatment. Posterior urethral distraction defects are commonly seen with anterior pelvic arch fractures. It has been classically taught that these fractures cause the prostatic apex to separate from the membranous urethra in the manner in which an apple is removed from its stalk. Newer data, however, show that these injuries typically occur more distally than the level of the prostatic apex [5, 6]. The level of the distraction defect is usually found just proximal to the departure of the bulbous urethra from the membranous urethra, and thus spares the external urinary sphincter. As in a vesicourethral distraction, this injury leads to extensive fibrosis interposed between the two distracted ends of the urethra and is resistant to endoscopic management.

Diagnosis and evaluation

Patients who have urethral strictures most often present with obstructive voiding symptoms, urinary tract infections (UTIs), hematuria, dysuria, and/or urinary retention. Compensatory hypertrophy of the detrusor may initially allow patients to void through a narrowed urethral lumen with few symptoms. Additionally, some degree of decreased urethral caliber may not significantly affect the flow dynamics. Patients may not develop significant symptoms until a reduced urethral caliber of 10–12F is reached. Many of these patients will relate an insidious onset of voiding symptoms before progressing to obstructive symptoms or complete obstruction.

First, it is important to question the patient as to the history of trauma, especially straddle trauma. A history of urethral infection, previous urethral, prostate or bladder surgeries, and previous catheterizations should be noted. A thorough genital examination should also be performed. Stigmata of hypospadias, lichen sclerosis, previous surgical interventions, and spongiofibrosis may be found. These clues revealed by history and physical examination may give the practitioner additional information as to the etiology of the disease process. This is quite important, as strictures of different etiologies may behave differently when treated.

Prior to any invasive manipulation or investigation, the state of the urine with regards to presence of microorganisms should be assessed, if possible. When the patient is in retention, this may not be feasible and broad-spectrum antibiotic coverage should be given prior to any attempt at catheterization, endoscopy or retrograde urethrography. Urine should be sent for culture when obtained. If it is a nonemergent situation, care should be taken to sterilize the urine prior to proceeding with investigation. In cases of colonization, such as exists in patients with chronic indwelling suprapubic cystostomy catheters, prophylactic doses of culture-specific antibiotics should be given. This is done not with the intent to eradicate colonization, but rather to prevent septicemia during the manipulation.

Passing a urethral catheter is a commonly attempted procedure when a patient cannot void. If the catheter does not pass, the nature of the obstruction is determined by dynamic retrograde urethrography. Many cases are managed with acute dilation, but this may not be in the best interest of the patient. When there is doubt, the nature of the stricture should be determined. A suprapubic cystostomy catheter can be used to treat the acute retention and give time to plan more appropriate treatment. No longer is blind passage of filiforms or blind dilation considered acceptable. The anatomy of the stricture must be determined either through advanced imaging or flexible endoscopy, which at the least, allows the stricture to be visualized and a guidewire to be passed under direct vision through the lumen. In this manner, dilation is not done "blindly," but with the wire to direct the dilators into the true lumen.

In addition to etiology, the location, length, depth, and density of the stricture (spongiofibrosis) or stenosis must be accurately determined in order to develop a workable treatment plan. The length and location of the stricture can be determined with traditional radiography, urethroscopy, and/or ultrasonography. Some feel that the absolute length of spongiofibrosis may not be evident by ultrasound evaluation alone. Contrast-enhanced studies may be further complemented by the addition of ultrasound studies and together these are accurate in determining the length of narrow-caliber annularity [7]. Contrast studies of the urethra are best carried out by or under the direct supervision of the surgeon responsible for treatment of the patient. The depth and density of the scar in the spongy tissue are difficult to determine, but are subjectively best evaluated by physical examination, contrast-enhanced studies that show the appearance of the urethra, and elasticity and appearance of the mucosa by endoscopy. While magnetic resonance imaging (MRI) and ultrasonography have been used to help characterize the degree of spongiofibrosis and location of the defect, we find these studies to rarely influence the treatment plan developed with traditional radiography and endoscopy.

At our center, imaging includes retrograde urethrography as well as voiding cystourethrography. The patient is placed in a steep lateral oblique position as anteroposterior images often can miss lesions or misrepresent their length. Even with gentle technique, extravasation during retrograde urethrography is possible in patients in whom the urethra is markedly inflamed. For this reason, contrast studies should be carried out with contrast that is suitable for intravenous injection and used either directly from the bottle or diluted according to the manufacturer's guidelines. It should also be understood that during contrast-enhanced urethrography, more than one projection may be necessary to visualize the stricture. Realtime ultrasound evaluation of the urethra after it has been filled with a lubricating jelly or saline has been described by Morey and McAninch [7, 8]. It is a misconception, however, that ultrasonography always directly visualizes the spongiofibrosis. Morey and McAninch, however, believe that ultrasonography of the bulbous urethra possibly more accurately determines the length of the stricture, which is important in considering an anastomotic repair [7, 8].

An initial endoscopic examination with the flexible cystoscope may be necessary after the contrast studies to evaluate the urothelium and assess the degree of spongiofibrosis. A pediatric cytoscope is a very useful tool to help traverse an area of narrow-caliber disease without having to dilate it, as dilation may not be ultimately beneficial. Care should be taken to avoid inciting inflammation of a particularly narrow stricture by passage of the pediatric endoscope. This may cause temporary edema and lead to an episode of acute retention. In the patient who cannot void and who has a suprapubic tube, combined contrast studies with endoscopy are helpful in defining the stricture anatomy (Figure 139.5). This evaluation allows delineation of the proximal point of the stricture by endoscopy, and the distal point by retrograde urethrography done simultaneously.

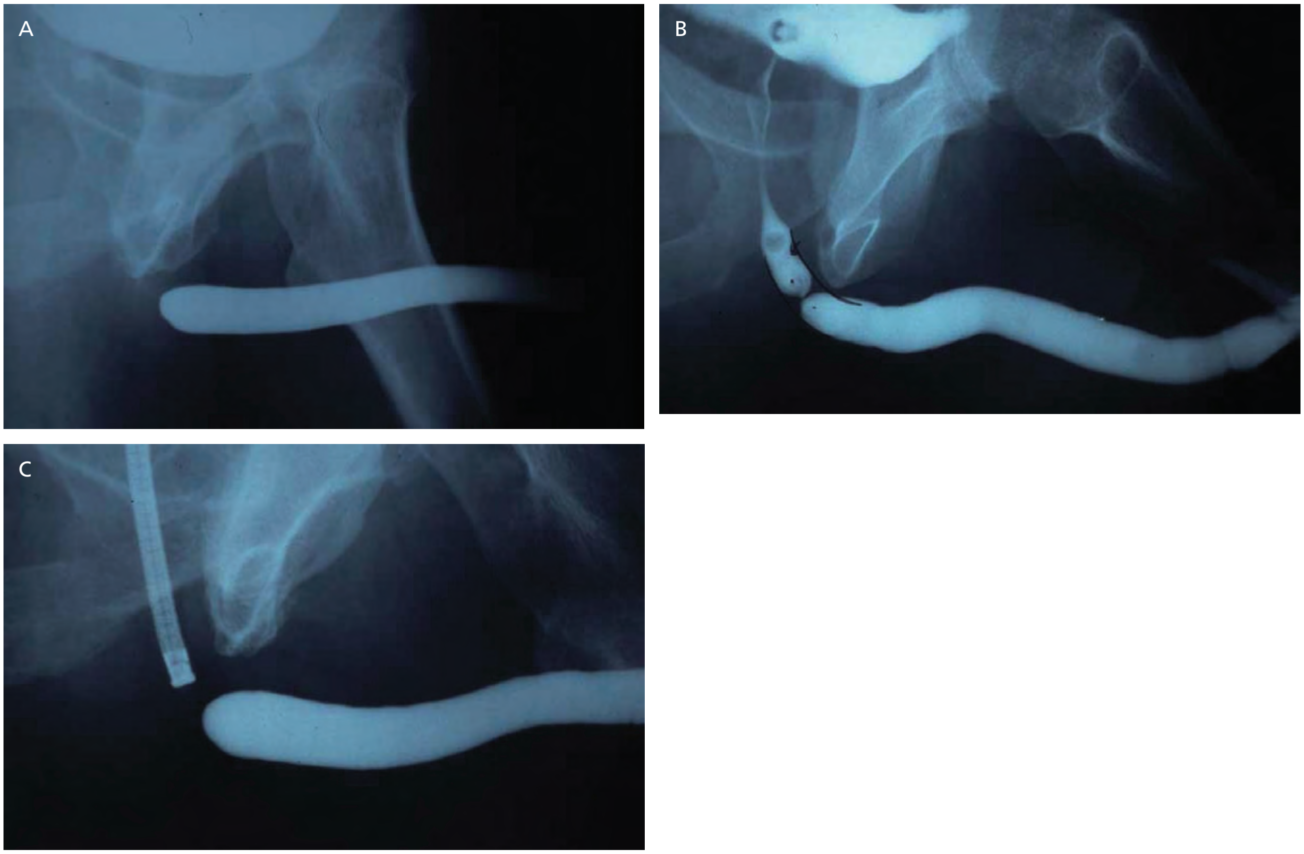

Figure 139.5 Series of radiographs demonstrating the usefulness of the combination of contrast enhancement with endoscopy. (A) A retrograde urethrogram shows a totally obliterative process involving the proximal bulbous urethra. (B) The patient was successful in relaxing to void; however, there is a suggestion of a wide-caliber annular area proximal to the obliterative process of the bulbous urethra. (C) Endoscopy through the suprapubic cystostomy tube clarifies the anatomy of the proximal urethra and demonstrates the length of the obliterative process.

In selected patients, in whom long-standing outlet obstruction is suspected or the degree of urethral obstruction does not correlate with symptoms, urodynamic studies may be warranted prior to treatment. Compensatory detrusor hypertrophy in cases of long-standing outlet obstruction may lead to myogenic detrusor failure. In this case, the patient may not void despite correction of the obstructive process. Correction may facilitate intermittent catheterization and thus may be appropriate, but this is an outcome that should be clearly understood, if possible, by the patient prior to treatment. Likewise, when the degree of symptoms is more severe than would be expected from the degree of luminal narrowing, suspicion is raised for bladder dysfunction or concomitant prostatic obstruction. Video urodynamics may be helpful to elucidate the level of obstruction, especially if prostatic or bladder neck hypertrophy is present. In these cases, treatment of the urethral narrowing alone may not alleviate obstructive symptoms. Additionally, medical treatment of the prostate or bladder neck may decrease or resolve obstructive symptoms without the need for treatment of the urethral pathology.

Treatment

Both the patient and the physician must have a good understanding of the goal of treatment before the treatment choice is made. To this end, treatment options should be discussed with the patient, with care taken to emphasize the anticipated outcome with regard to palliation versus cure. Some patients may prefer palliative stricture management and choose to have periodic dilations in the office, at home, or in the hospital, rather than undergo technically detailed open surgery. Others may have cure as a goal and choose open surgical management. The information gained in the evaluation of the stricture is imperative in discussing treatments and expected outcomes with the patient. Also, a thorough knowledge of the etiology of the process is needed for counseling on risk of recurrence. Many well-described reconstructive procedures utilized today have long-term success rates in excess of 90% and may be used to repair many common types of strictures.

Dilation

Filiform dilators have been used for years. The filiform leader is passed initially through the stricture. If the straight tip does not pass, there are spiral tips that may allow passage. The safest way to pass the filiform leader is under direct vision. Also available are a myriad of metal and plastic dilators that may be passed in a similar fashion. Again, blind dilation should be discouraged [9].

The least traumatic method would be soft dilation techniques over multiple treatment sessions. We believe the safest method currently available is the use of urethral balloon dilation. These catheters may be attached to a filiform tip or passed over a guidewire with an integral Coudé tip. For the patient's initial dilation we prefer cystoscopy under anesthesia to allow for placement of a wire which facilitates safe passage of the balloon. In this setting the stricture is truly dilated. A home balloon obturation protocol can then be performed by the patient with the goal of maintaining the operative dilation. This minimizes the amount of repetitive trauma to the urethra and allows the healing process to stabilize, while being periodically opposed by the home balloon protocol. We prefer to have the patient use a steroid cream as lubricant for the balloon to decrease urethral inflammation. Additionally, oral antibiotic therapy may be used as an anti-inflammatory agent. Initially, the patient starts the obturations several times daily, then daily, then weekly, and then steadily decreasing the frequency as the process allows. This protocol allows for treatment of most types of urethral stricture/stenosis, although as previously stated, distraction defects of the posterior urethra are very difficult to manage in this fashion.

Meatal dilation in cases of meatal stenosis secondary to lichen sclerosis has also been proven to be an effective management strategy. It is quite easy for patients to perform home dilations using a graduated dilator lubricated with steroid cream. The patient must be thoroughly counseled on proper technique and the goals of dilation if this is to be successful. Frequent, nonaggressive episodes of dilation are favored over periodic forceful episodes. In addition to limiting trauma, the patient will usually find this to be more comfortable, as very little pain and no bleeding should be encountered. By limiting the amount of distal obstruction, proximal dilation and extravasation should also be minimized, thus decreasing proximal inflammation and possibly stricture formation. With initial persistence and patience, many patients find that eventually the meatal process stabilizes and only infrequent interventions are needed.

Dilation has been shown to be equal to direct vision internal urethrotomy (DVIU). Steenkamp *et al*. performed a randomized prospective trial comparing DVIU to filiform dilation in 210 men with urethral strictures [9]. Their results show a 16% greater recurrence rate at 36 months in the dilation group compared to the DVIU group, and a 10% higher recurrence rate at 48 months. Stormont *et al*., in a retrospective review of 199 nonrandomized patients with short bulbar strictures treated with dilation or DVIU, showed that the success rates were equal. At 3 years the success rate for the dilation group was 65% compared to 68% for the DVIU group

[10]. Due to the fact this was a nonrandomized retrospective review, there was some selection bias which cannot be excluded.

Complications associated with urethral dilations include cystitis, epididymitis, hemorrhage, recurrent urethral stricture, and false passage.

Internal urethrotomy

Internal urethrotomy refers to a procedure that opens the stricture by incising it transurethrally. The procedure involves incising through the scar to healthy tissue to allow the scar to expand with the goal that it will heal with a larger caliber. The process of incision essentially sets off a race between epithelialization and wound contracture. If the incised areas epithelialize, i.e. heal by secondary intent, before the wound contracts, then the area will stay open. If not, then the stricture recurs. As with dilation, the goal is to minimize trauma to the unaffected adjacent tissues.

The technique of a cold knife urethrotomy is a relatively simple procedure using a 0° or 12° scope with a 19 or 21F sheath. It is important to use isotonic fluid, usually normal saline, to limit the risk of hyponatremia if there is extravasation, and possibly the isotonic fluid effect on the tissues during the procedure may be less injurious. A glidewire or ureteral catheter should first be passed through the stricture into the bladder. Something should always be passed through the area before incision to maintain identification of the true lumen. Many surgeons will make the incision at the 12 o'clock position, although we question this because of the location of the urethra within the corpus spongiosum (see Figure 139.2). On cross-section of the corpus spongiosum, the thinnest portion is the anterior aspect between 10 o'clock and 2 o'clock. Therefore, a deep incision could penetrate through the corpus spongiosum into the intracrural space, or corpus spongiosum if the incision is further distal. These incisions into the corpora cavernosa have been associated with erectile dysfunction, likely due to veno-occlusive dysfunction. If it is felt that the spongiofibrosis is deep, an internal urethrotomy will not be curative. We prefer using multiple small radial incisions at 10, 2 and 6 o'clock, without cutting too deep into the corpus spongiosum.

Cure rates following DVIU initially were considered to be 80% or above, and this initially caused an increase in the use of internal urethrotomy [11]. Additionally, many practitioners were more familiar with this type of management as compared to open urethral reconstruction. The idea of a "reconstructive ladder" was thus popularized. Many considered that it was appropriate to perform multiple endoscopic procedures on recurrent strictures *in lieu* of opting for open reconstruction. This has since been proven to be faulty logic. Subsequent studies have borne out the issues of endoscopic success and the effect of multiple endoscopic treatments on open reconstruction. Success rates following DVIU have been shown to vary between 35% and 90%, possibly dependent on the length of stricture, previous treatments, and length of follow-up assessed.

The nature of the strictures being treated with internal urethrotomy has been poorly reported and with various endpoint parameters. This makes comparative assessment difficult because the literature is not clear as to the goal of internal urethrotomy. For many, internal urethrotomy is considered successful if it offers temporary relief. Santucci and McAninch reported curative success rates to be approximately 20% using actuarial techniques [12]. Pansadoro and Emiliozzi as well as others have shown that DVIU is curative in 30–35% [13]. Their study did not show any long-term success for strictures outside of the bulbar urethra. Data show that strictures in the bulbar urethra that are less than 1.5 cm in length and are not associated with dense, deep spongiofibrosis can be managed with internal urethrotomy with 74% success rates. It has been shown in multiple studies that success of urethral reconstruction is diminished by multiple prior urethral dilations or internal urethrotomies [14–16, Boccon-Gibod, L. Personnel communication, 2005]. Some have shown a single internal urethrotomy prior to an open urethral reconstruction to be cost-effective [17]. Others have refuted this finding and have found urethrotomy to lengthen the stricture and make subsequent reconstruction more difficult [18]. In any event, a single attempt at urethrotomy is probably warranted if all of the available criteria favor the chance of success. If these criteria are not favorable, it may not be cost-effective or of any benefit to the patient.

Recurrence of the stricture is the most common complication associated with internal urethrotomy. Complication rates following internal urethrotomy range from 8% to 27%. Complications associated with internal urethrotomy include dysuria, UTI, septicemia, minor bleeding, retention, scrotal abscess, extravasation, urinary sepsis, and epididymo-orchitis. Erectile dysfunction has also been reported as a complication in up to 11% of patients after an internal urethrotomy. Possible causes are fibrosis after extravasation with infection or injury to the cavernous nerves with deep incision. Other more uncommon complications include a urethral–internal pudendal artery fistula leading to high-flow priapism, severe hemorrhage, and urosepticemia. These unusual complications are usually associated with aggressive internal urethrotomy.

Since the success rate with internal urethrotomy is so poor, several techniques have been employed to oppose the wound contraction. One option is to leave an indwelling Foley catheter for 6 weeks after urethrotomy in the hope that the urethra will mold around the catheter as it heals. Studies have shown that the failure rates with this technique are equal to those when a catheter is left for 3–7 days. Another option used to oppose the wound contraction forces is home self-catheterization. The catheter is left in place for 3–7 days and once removed, the patient is started on a urethral catheterization program. This usually requires more catheterizations in the first 3–6 months, but the number tapers thereafter. It is our experience that once the patient stops the self-catheterization, the stricture recurs, but this technique can effectively manage motivated patients. However, as already discussed, protocols using catheters or balloon obturation can successfully manage patients.

It has been shown that the length of follow-up as well as length and location of the stricture are of utmost importance in determining success. Boccon-Gibod and Le Portz had a 56% cure rate at 6 months and 43% at 12 months, but only 25% at 2 years [11]. Albers *et al*. confirmed the lower success rates over time, with a success rate of 95% at 6 months but only 55% at 38 months [15]. With a repeat urethrotomy the success rates appear to decrease. One study has shown a success rate of 75% with the initial treatment but only 45% for a secondary treatment. Length of stricture also has a significant effect on recurrence. Steenkamp *et al.* showed success rates at 12 months for strictures greater than 4 cm to be less than 20% compared to 40% for strictures of less than 2 cm [9]. Finally, a number of studies have shown higher success rates with strictures in the bulbar urethra compared to the penile urethra.

Dilations and/or urethrotomies may be used as part of a palliative strategy almost anywhere in the urethra. With some persistence on the part of a motivated patient and a favorable stricture etiology, some strictures may only need periodic maintenance. Conditions such as lichen sclerosis, which have a high propensity for recurrence, are often treated in this fashion as few if any "curative" options have been discovered. If either of these methods, however, is being used with a notion of curative intent, the characteristics of the process must be carefully evaluated. The highest reported success rate is in short (<1.5 cm) mucosal strictures of the proximal bulbous urethra, as mentioned above. Attempts to manage more distal anterior urethral strictures or stenoses of the posterior urethra will likely have no durable result. Additionally, if a single attempt at dilation or urethrotomy fails, subsequent attempts should also be expected to fail. Particularly dismal are the results after dilation or incision of a vesicourethral distraction defect or posterior urethral distraction defect. Incision of a bladder neck stenosis after TUR or radical prostatectomy may be the only exception to the rule for posterior urethral stenoses, in that these do respond well to endoscopic management [19].

Lasers

The ideal laser for use in the treatment of urethral strictures is one that totally vaporizes the scar, exhibits negligible peripheral tissue destruction, is not absorbed by water, and is easily propagated along the fiber. As with previously described treatment modalities, care should be taken to minimize injury to adjacent tissues as this may worsen the disease process. There are several types of lasers used for the treatment of urethral stricture disease, including carbon dioxide, argon, KTP, neodymium (Nd):YAG, holmium:YAG, and excimer lasers. Although the carbon dioxide laser appears to be ideally suited, it must be used with a gas cystoscope, which carries the potential risk of carbon dioxide embolus.

For both the argon and Nd:YAG lasers, the mode of action is thermal necrosis, which has significant potential for peripheral tissue injury rather than vaporization. The Nd:YAG laser is also used with a bare fiber in contact mode, which carries a risk of forward scatter. Used in the contact mode, the YAG energy is transferred to a sapphire tip which will obliterate the scar by vaporization of the tissue. There are no data showing improved results for obliteration compared to DVIU.

A KTP laser is essentially a Nd:YAG laser that has passed through a KTP crystal, resulting in a reduced depth of penetration. The internal urethrotomy with the KTP laser is done by passing the fiber over the scar tissue. The holmium:YAG laser has properties similar to the KTP laser and provides both direct cutting and vaporization with minimal scatter. Numerous studies have shown the holmium:YAG laser to be safe in the treatment of urethral strictures, although success rates appear to be comparable to DVIU performed with a "cold knife" [20, 21].

The excimer laser is a vaporizing laser with little forward scatter or peripheral tissue necrosis. Little experience with this laser has been reported but its characteristics warrant further investigation.

The results of laser urethrotomy are mixed, but with the advent of new lasers future data may show improved results. A laser with perfect characteristics for treating urethral stricture disease does not seem to exist at this time. Currently, no data exist to show superiority of laser urethrotomy over other techniques. Its indication for usage is similar to that of dilation or cold knife urethrotomy, as discussed above. Short bulbous strictures, prostatic urethral stenoses, and bladder neck stenoses are the most likely to respond to laser urethrotomy. Small to no durable results should be expected from utilizing laser urethrotomy in more distal anterior urethral strictures, vesicourethral distraction defects or posterior urethral distraction defects.

Urethral stents

As discussed above, when wounds heal, the healing process may lead to contraction. Urethral stents (removable or permanent) can be used to oppose the forces of wound contraction after internal urethrotomy or dilation.

The UroLume® stent (American Medical Systems, Minnetonka, MN, USA) is a permanent, biocompatible, nonmagnetic superalloy woven into a tubular mesh that is self-expanding to 42F. After being deployed, it is incorporated into the wall of the urethra and the corpus spongiosum. The UroLume stent is used in patients with short bulbar strictures of less than 3 cm in length and at least 1 cm from the external sphincter. Available data show that the stent is best employed for short strictures associated with minimal spongiofibrosis. Initial results for the UroLume stent were encouraging with retreatment rates decreasing from 75.3% to 14.3% after insertion in 105 patients who were followed for 1 year [22]. Of the 179 patients originally enrolled, 24 patients completed 11-year follow-up, and the overall success rate at 11 years was less than 30% [23]. This was confirmed in a study with 10-year follow-up from the Netherlands, which reported that only two of the 15 patients implanted were satisfied [24].

Complications associated with permanently implantable stents are unique. Many of these complications occur when the stents are placed outside the bulbous urethra. This is especially true in the pendulous urethra or when the stent is used for a vesicourethral or posterior urethral distraction defect. These complications may include pain with intercourse and sitting, perineal discomfort, and painful erections. Other complications include recurrent stricture, hyperplastic tissue growth, migration of the stent, recurrent UTIs, dysuria, calculus formation, and hematuria. Contraindications to UroLume placement include previous substitution urethral reconstruction where skin has been incorporated into the reconstruction. These patients will experience a virulent hypertrophic reaction of the skin, which can lead to a severe functional recurrence of the stricture. Other patients who are poor candidates for the UroLume stent are those whose strictures are associated with deep spongiofibrosis, which includes patients with straddle injuries and urethral distraction injuries. We consider that UroLume is indicated only for patients with short bulbar strictures whose medical problems preclude open urethral reconstruction.

The concept of a temporary stent is appealing compared to a permanent stent. The concept is to leave the stent in place long enough to act as a mold until stabilization of the wound, preventing scar contraction during the healing process. The Memokath urethral stent (PNN Medical, Kvistgaard, Denmark) is made of nitinol and is currently available in Europe, but not in the USA (where a large randomized trial has just been completed). The Memokath is a thermoexpandable stent. Once placed in position, prewarmed saline is flushed through the stent and urethra, expanding the stent and the bell-shaped ends, which secures the stent in place. The main body of the stent is 24F, and with the bells 44F. The tight spiral structure of the stent prevents urothelial ingrowth

Conclusions

Initial evaluation of a patient with a urethral stricture/stenosis should include a thorough history and physical examination. Length of duration of symptoms, history of trauma, infection or surgery should be noted. The genitalia should be inspected for scars, inflammatory changes, and stigmata of previous treatment, and the entire course of the corpus spongiosum should be palpated and assessed for fibrosis. Thorough radiographic and endoscopic evaluation should also be performed. After determining the length, location, depth, density, and proposed etiology of the process, the patient should be counseled as to palliative versus curative intent of any intervention. In cases of acute urinary retention, thought should be given to placement of a suprapubic cystostomy catheter *in lieu* of dilation in selected patients.

Only in very carefully selected processes should endoscopic attempts at management be considered to have a reasonable chance at cure. While both dilation and DVIU have similar rates of success, these rates are only favorable in short, superficial, noninflammatory, proximal bulbous strictures. Any other attempts should be considered palliative. Multiple attempts should not be made in patients who are considered candidates for an open reconstructive procedure. Certain types of strictures, such as those of the meatus and fossa navicularis, may respond well to interval dilation. Other processes, such as posterior urethral or vesicourethral distraction injuries, typically do not. That said, endoscopic management may be very reasonable for a variety of patients and is appropriate as long as the goals are clearly stated and understood.

No laser or urethral stent is currently available in the USA that has been shown to drastically revolutionize endoscopic management of urethral stricture/stenosis. Further study is needed to identify and replicate the characteristics of these tools that provide ideal minimally invasive management of this often difficult disease process. For many patients who desire a curative procedure, open surgical reconstruction remains the gold standard.

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CHAPTER 140

Bladder Neck Contracture Following Radical Prostatectomy

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Introduction

The formation of a bladder neck contracture (BNC), or anastomotic contracture as it is often called, following radical prostatectomy can be a devastating complication. There is no consensus regarding the definition of BNC, which makes an accurate complication rate hard to derive from the literature. The incidence is reported to range from 0.5% to 32%, and the definition of a BNC ranges from urinary retention to a pinhole circular narrowing of the urethra above the external sphincter [1–6]. In many studies, the inability to pass a 16F cystoscope defines a BNC.

The onset of a BNC is usually heralded by a diminished force of stream, urinary frequency, progressive straining to void or frank urinary retention. In most cases the symptoms occur 6–8 weeks after surgery. As Webb *et al*. point out in their publication on laparoscopic versus robot-assisted radical prostatectomy-induced BNCs, “this [timeline] is consistent with the normal healing process of fibrosis and wound contracture” [6]. Urethral catheter placement is attempted and when this fails, flexible urethroscopy is performed to confirm the BNC and visualize the caliber and condition of the narrowed urethral lumen at the urethral anastomosis.

Incidence

The incidence of urethral stricture after primary treatment for prostate cancer was examined utilizing the CaPSURE database in 2007 [7]. Radical prostatectomy was performed in 3310 men with 277 (8.4%) developing a urethral stricture requiring treatment. In most cases the initial therapy was urethral dilation and in 42% of cases the BNC code was used and entered into the database. Even though academic practices report lower incidences of BNC, ranging from 2.5 to 4.8%, reviews of ICD-9 and CPT codes from the Medicare database note a BNC rate of 22%, including for high-volume surgeons (>60 radical prostatectomies/year) [8]. The incidence of BNC following open radical retropubic prostatectomy is higher than the reported incidence emerging from the robot-assisted radical prostatectomy literature (see below).

In 1994 Jonler *et al*. surveyed 93 consecutive men for complications following radical prostatectomy, with responses from 92% of the patients [9]. Treatment of a BNC was reported in 20% of the men and more than half of the group had undergone more than one procedure. More recent large contemporary single-surgeon series have reported BNC rates below 10% following open radical prostatectomy. The BNC incidence for Kirby was reported to be 9.4% following radical prostatectomy in 510 consecutive men [10]. In the majority of cases a single dilation of the BNC was effective, with only 19% requiring more treatment, along with five men utilizing self-catheterization for several months. In 2009 Erickson *et al*. reported the latest update on Catalona’s single-surgeon series of 4132 men undergoing open radical retropubic prostatectomy [11]. The overall incidence of BNC was 2.5% with a lower rate (1%) in the last 500 patients undergoing surgery.

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Table 140.1 Multifactorial causes of bladder neck contracture following radical prostatectomy.

Technical	Clinical
Surgical experience	Urinary tract infection
Vest technique	Previous TURP
"Stomatization"	Cigarette smoking
Anastomotic urine leak	Coronary artery disease
Non-nerve sparing RRP	Diabetes mellitus
Bladder neck reconstruction "racket handle"	Hypertension Radiation therapy
Pelvic hematoma	Hypertrophic scar former
Large volume blood loss	Age >70 years
Suture type and technique	Obesity
Duration of indwelling catheter	Higher clinical stage Higher PSA
Caliber of reconstructed BN	Radiation therapy

RRP, radical retropubic prostatectomy; TURP, transurethral resection of the prostate; PSA, prostate-specific antigen.

Etiology

The exact cause of BNC is not known and multiple factors have been associated with its development (Table 140.1). Providing direct apposition of the urethral mucosa to the bladder neck and avoiding a "gap," especially at the posterior margin, was the technical objective behind mucosal eversion or "stomatization" described in the open radical prostatectomy literature. "A well-vascularized and water-tight suture line obviously is ideal for optimal healing of the anastomosis" [10]. Borboroglu *et al.* hypothesized that men with potential microvascular compromise could be at increased risk, and implicated several comorbidites increasing the risk of BNC after radical prostatectomy [12]. Poor healing of the anastomosis and scar formation secondary to local ischemia from microvascular disease was the central theory behind their prospective study. In their series of 467 men undergoing radical prostatectomy, 11.1% developed a BNC. Smoking at the time of radical prostatectomy in 62 men was associated with a 26% BNC rate, compared to 9% in the nonsmokers, a statistically significant difference. In addition, they showed higher rates of BNC in men with coronary artery disease, hypertension, and diabetes mellitus. Current smokers and men with coronary artery disease were shown clearly to be at much higher risk for BNC following radical prostatectomy. Other clinical factors to consider include age greater than 70 years and obesity, both of which were significant risk factors for BNC [7].

Early urinary retention following radical prostatectomy has been shown to be an early risk predictor for BNC formation [13]. From 1998 to 2004, investigators at Michigan studied 1289 men following radical prostatectomy. Men presenting with urinary retention occurring within the first week after catheter removal were 4.7 times more likely to develop a symptomatic urethral stricture (94% BNC). The overall population had a 9.9% risk of BNC, while 36.4% of those with early retention formed urethral strictures. The authors recommended educating postoperative patients with early retention about their increased risk of developing an anastomotic stricture by explaining the early signs and symptoms of obstruction.

Technical factors

An overall incidence of BNC following radical prostatectomy of 20% was reported by Levy *et al*. who retrospectively reviewed 143 cases, focusing on their anastomotic technique and postoperative evaluation with voiding cystourethrograms [14]. Three surgical techniques were explored, including radical perineal prostatectomy (15 patients), radical retropubic prostatectomy (93 patients) with a direct anastomosis and bladder neck reconstruction, and radical retropubic prostatectomy with a modified Vest anastomosis (35 patients). Voiding cystourethrograms were performed at 3 weeks to evaluate for the presence or absence of contrast extravasation at the anastomosis. The Vest technique resulted in the lowest incidence of urinary extravasation (6%), but had the highest BNC rate (27%). The lack of direct mucosal apposition with the Vest method led to the abandonment of this technique. Furthermore, the authors remarked that urinary extravasation was a sign of a persistent anastomotic gap and there was no increase in BNC incidence as long as the catheter was left in place until the urinary extravasation resolved.

The caliber of the anastomosis and the technique for reapproximating the urethra to the bladder are proving to be important factors to consider in the prevention of BNC. Many surgeons considered that a bladder neck-sparing operation would preserve continence, so attention was paid to preservation of the bladder neck as it was dissected away from the base of the prostate to yield a small-caliber anastomosis. Most contemporary series dispute this concept and have embraced a nonsparing approach to the reconstruction to allow tailoring of the bladder neck to a wider-caliber anastomosis. Eastham *et al.* modified their surgical technique in 1990 to embrace a 24–26F tailored bladder neck, which lowered their BNC rate from 20% to 6%; they remarked that the bladder neck played little if any role in the long-term continence rate in 390 men treated by open radical prostatectomy when compared to 191 men treated before the introduction of the modification [15]. Catalona *et al.* increased the size of their reconstructed bladder neck from 18F to 24F in 1870 consecutive radical retropubic prostatectomy patients and their BNC rate dropped from 10% to 1% [16]. In addition, many surgeons are concerned about higher positive margin rates with bladder-neck sparing. Tapering or tightening the anastomosis appears to increase the BNC rate and few studies have demonstrated any advantage in terms of improved continence from using a narrowed anastomosis.

One early tenet of the anastomotic surgical technique was mucosal eversion sutures or "stomatization." For experienced surgeons, BNC rates have declined with experience. However, the recent introduction of laparoscopic and robot-assisted radical prostatectomy has markedly lowered the BNC rates. In fact, Forster *et al.* embraced a continuous anastomotic technique, based on this emerging trend, in their open radical prostatectomy patients and avoided mucosal eversion in 39 consecutive patients [17]. There were no BNCs in their series. Harpster and Brien described their series of 72 patients utilizing a continuous running anastomosis following open prostatectomy [18]. With a mean follow-up of 31 months there were no reported BNCs and in most men the catheter was removed 4–6 days following prostatectomy. There is compelling evidence, based on large series of laparoscopic and robot-assisted radical prostatectomies, that mucosal eversion and interrupted sutures are not necessary and may actually contribute to higher BNC rates.

Failure of primary radiotherapy, whether external beam radiation alone or with brachytherapy, followed by salvage prostatectomy leads to a much higher incidence of BNCs. Gotto *et al.* compared a series of men undergoing open radical prostatectomy versus failed primary radiotherapy followed by open salvage radical prostatectomy and noted BNC rates of 3% versus 26%, respectively [19]. Furthermore, the number of procedures to manage the BNC and the invasiveness of the treatment was significantly greater in the salvage group of men in whom radiotherapy failed to cure their prostate cancer. The BNC rate was elevated much like that seen in men with prior transurethral resection of the prostate (TURP) followed by radical prostatectomy.

Management

Prevention of a BNC is the best method of management. While most BNCs present early following catheter removal and can be managed with a single urethral dilation, those that are dense and recurrent can be a major source of life-long morbidity. Unfortunately, the presence of a BNC is often associated with some degree of post prostatectomy incontinence. Evaluation of the BNC should include a urinalysis and postvoid residual urine measurement. The presence of a urinary tract infection should be treated prior to any instrumentation.

The initial treatment of a BNC is usually dilation with urethral sounds or filiforms and followers in the office. Visualization of the urethral obstruction with flexible cystoscopy should precede blind dilation whenever possible (Figure 140.1). Post-prostatectomy sphincter strictures can be mistaken for a BNC and "they are the most difficult of all strictures to manage effectively and the prime consideration must be the preservation of its all-important residual intrinsic sphincteric function (upon which the patient's continence depends), rather than the definitive resolution of the stricture itself" [20]. Without careful inspection under direct vision, it is not possible to differentiate a sphincteric stricture from a BNC. Along with a much higher risk of inducing sphincteric incontinence, the tendency to restenose is higher with sphincteric strictures since tonic closure of the muscle narrows the urethral lumen during bladder storage. Careful and limited dilation of the sphincteric stricture is the method of choice as opposed to internal urethrotomy.

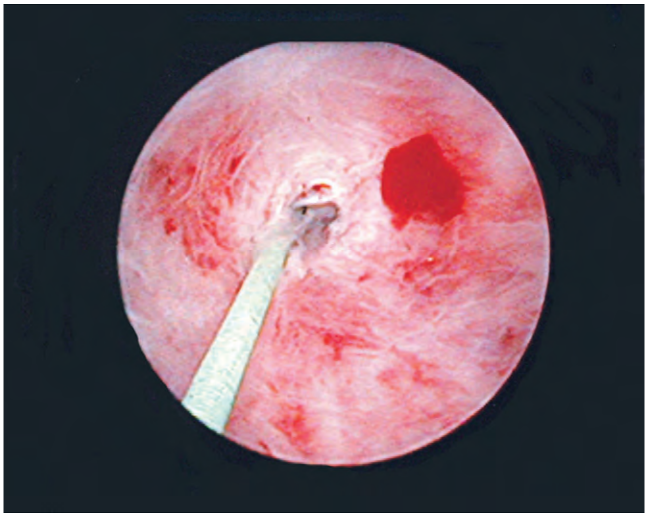

Figure 140.1 Tight anastomotic contracture with guidewire in the lumen.

In most cases, a single urethral dilation manages the BNC with resolution of symptoms and incomplete voiding [21]. Repeated office-based BNC dilation is not warranted. With the exception of soft self-catheterization to maintain urethral patency, especially when a stricture involves the urethral sphincter, routine dilation rarely "cures" the BNC. Failure of initial urethral dilation is followed by operative intervention with cold-knife incision of the BNC. Radial incisions, through the scarified urethra down to healthy tissue, at three sites are the preferred method for opening the BNC. The use of simultaneous transurethral steroid injection into the stricture has not been studied in a randomized fashion, although several investigators have touted the use of triamcinolone acetonide (200 mg) for this purpose. One small clinical trial investigated botulinum toxin A

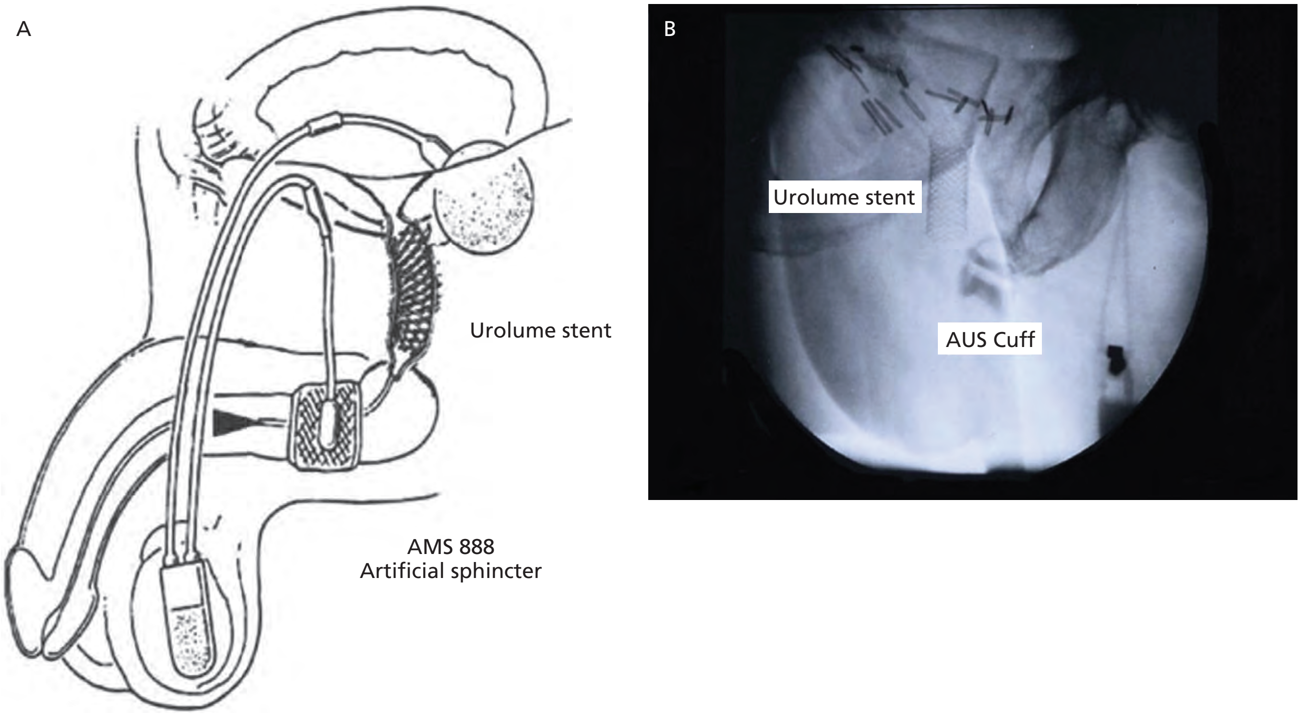

Figure 140.2 (A, B) Urethral stent at the bladder neck with artificial urinary sphincter (AUS).

injection in men with bladder neck contractures and showed some early positive results where the toxin helped maintain patency of the anastomosis [22].

Some investigators prefer laser incision of the BNC over use of the cold knife, although there are no studies supporting one method over the other. Recently, Eltahawy *et al.* managed recurrent anastomotic contractures following radical prostatectomy with holmium laser incision and steroid injection [23]. The success rate ("well healed and widely patent") for recurrent anastomotic strictures in 24 men treated with this method was 83% at a mean of 2 years. Artificial urinary sphincters were implanted in 11 men, illustrating the common association of urinary incontinence with BNC.

If initial urethrotomy fails to manage the BNC, many clinicians resect the BNC to try and maintain patency. We prefer to avoid heat whenever possible in the treatment of a BNC, as this can induce more scar formation than was present with the initial BNC. The failure of BNC resection to manage recurrent BNCs effectively led us to consider using the UroLume® stent (American Medical Systems, Minnetonka, MN, USA) in the late 1990s. The UroLume stent was approved for use in prostate-mediated outlet obstruction, detrusor–sphincter dyssynergia, and short strictures in the bulbous urethra, but not for BNCs. For men faced with urinary diversion as the next step to manage their recurrent BNC-induced obstruction, we offer the UroLume stent as a potential option.

Elliott and Boone reported their series of nine men with recurrent BNC and concurrent post-prostatectomy incontinence treated by initial incision and UroLume stent placement followed by delayed insertion of an artificial urinary sphincter [24] (Figures 140.2). The men were followed for a mean of 17.5 months. One patient had a recurrent BNC while the others maintained urethral patency and showed marked improvement in continence after artificial sphincter placement. Webster *et al.* at Duke utilized a similar staged approach in nine men with recurrent BNC in whom the UroLume stent was implanted followed by an artificial sphincter once the stent had epithelialized and the BNC was open and stable [25]. A larger series of 25 men with recurrent BNC and incontinence managed by UroLume stent placement was reported by Elliott *et al.* at the Mayo Clinic [26], with a median follow-up of 2.9 years. A single stent was adequate in 52% of the patients, while multiple stents (two to four) were used in the remainder, with an overall patency rate of 76%. Artificial urinary sphincters were placed in 23 men with quality-of-life improvement noted in 92%. This staged approach should be used with caution as the stents are difficult to remove and regrowth of scar through the stent is possible. Proper deployment of the stent across the BNC can be difficult in cases where the anastomotic stricture is fixed behind the pubis, preventing proper alignment of the deployment tool prior to release of the stent to span the entire BNC.

Careful patient selection and experience with UroLume stent placement are mandatory before considering this method to manage the severe recurrent BNC.

Surgical repair with excision of the BNC in an open setting usually requires a combined open approach from above and below. Very few reports have tackled this difficult surgical approach. McAninch *et al.* described their results with anastomotic urethroplasty in 19 men, with an overall success rate of 73% [27]. Nine men, in whom concurrent radiotherapy was employed, opted for stent placement for fear of poor healing with an open procedure. A combined open approach to complex bladder neck–prostatic contractures was described by Theodorou *et al*. with a mean operative time of over 4 h, which included artificial urinary sphincter placement to correct the inevitable incontinence with this surgical approach [28].

In our experience, most patients with severe and recurrent BNC who decline stent placement followed by an artificial urinary sphincter opt for urinary diversion. In selected cases, we offer a Mitrofanoff procedure with or without augmentation cystoplasty instead of ileal conduit diversion. The BNC is allowed to close and in most cases the patients remain dry per urethra.

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PART 8 **Incontinence**

CHAPTER 141

Bioinjectables for SUI (Stress Urinary Incontinence)

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Introduction

Recent improvements in our understanding of the underlying pathophysiologic mechanisms responsible for stress urinary incontinence (SUI) in women have led to the development of innovative new surgical methods for its treatment. Many are less invasive than prior techniques and appear to offer improved safety and shorter hospital stay, while maintaining the efficacy of traditional open incontinence surgery. Procedures using injectable periurethral bulking agents characterize this current trend toward less invasive surgical treatments. However, some recent reviews have shown a decline in the use of bulking agents [1].

History

Bulking agents have a long medical history in fields outside of urology. They have been used for gastroesophageal reflux, scars and wrinkles, as well as for patients with glottic insufficiency [2, 3]. Urethral bulking agents have been used to treat stress incontinence since 1983 when Murless used sodium morrhuate or cod liver oil as a sclerosing agent in the anterior vaginal wall of 20 patients, attempting to create an inflammatory response. Others used similar agents, but until 1973 this approach was seldom used. Berg [5] and Politano *et al.* [6] popularized the use of polytetrafluoroethylene (Teflon) through the 1970s. However, urethral bulking only became popular following the Food and Drug Administration (FDA) approval of bovine glutaraldehyde cross-linked collagen (Contigen).

Mechanism of action

Injectable agents appear to augment the urethral wall and thereby increase urethral resistance. The resulting improvement in urinary incontinence is not associated with a corresponding increase in voiding dysfunction. This is because the "seal" that is formed by restoring mucosal coaptation does not occlude the urethra. The urethra maintains the ability to funnel and open, with no change in detrusor pressure to initiate a flow. Interestingly, most agents are placed short of the bladder neck, within the smooth muscle layer in the zone of the continence mechanism.

Klarskov and Lose measured pressure and cross-sectional area in the urethra of women with SUI and mixed incontinence before and after urethral injection therapy, using a pressure profile reflectometer [7]. This novel technique detected a more significant increase in squeezing opening pressures in patients who had subjectively noted an effect. They suggested that injection therapy functions as a central filler volume that increases the length of muscle fibers and thereby the power of the urethral sphincter. The external sphincter consists of muscle fibers, collagen, vessels, and nerves, with a central component compressing the lumen [8]. An

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increased central filler volume will augment the sarcomere length of muscle fibers, strengthening muscle power up to a sarcomere length of 2.2 μm [9, 10].

Patient selection

The index patient for bulking should have demonstrated stress incontinence and evidence of intrinsic sphincter deficiency (ISD). While there exists some argument over a fixed versus a mobile urethra, most would agree that a relatively fixed urethra (nonradiated) may respond well to bulking. The patient with hypermobility may have some improvement, but usually the shearing force of a cough is too great to maintain dryness if mobility exists.

Traditionally, urethral bulking agents have been specifically indicated for SUI secondary to poor urethral sphincter function. This usually means a low Valsalva leak point pressure and limited urethral mobility. This indication is based on the fact that support is a key factor to consider in urethral bulking. Specifically, if there is poor vaginal support and significant mobility of the bladder neck/urethral complex, other options usually have better results. However, because bulking agents were originally considered to have greatest utility in these kinds of patients and subsequent reimbursement followed along those lines, it was some time before patients with hypermobility were studied in the USA in any detail. Herschorn *et al.* in Toronto demonstrated that the patient with hypermobility could derive benefit [11, 12]. In fact, no significant difference in outcomes was seen in patients with or without hypermobility in their studies. Interestingly, patients with hypermobility required less collagen for a successful outcome. Monga *et al.* reported on 60 women with genuine stress incontinence and urethral excursion ("mobility") of up to 25 mm [13]. Objective cure rates (according to urodynamic assessment) were 61% at 3 months and 48% at 24 months. Subjective success rates were 86% and 68% at 3 months and 24 months, respectively. A logical conclusion derived from these studies is that ISD can exist in the presence of hypermobility and that this alone should not be a criterion for exclusion from bulking therapy. There of course exists a gray area, where the patient and physician agree to use these agents fully anticipating a partial improvement in an otherwise poor surgical candidate.

Finally, in addition to physical examination, urodynamic studies need to be performed to document a low leak point pressure, as well as to rule out other sources of incontinence. Some reimbursement can be predicated on the documented leak point pressure. Ideally, video provides a look at the bladder neck and proximal urethra, confirming low urethral resistance.

Techniques

There have been numerous approaches to placement of urethral bulking agents, including intraurethral or transurethral, periurethral, and even transvaginal [14–16]. The two most common routes are intraurethral or periurethral, and the former is by far the most popular. Yet, two transurethral techniques evolved for a short time: the obvious visual approach and a "blind" technique. The nonendoscopic approach was designed ostensibly to eliminate operator variability. First described by Henalla *et al.*, a device was developed to control the placement of the injected material in predetermined areas [17]. This technique is rarely used today in the USA.

Faerber *et al.* reviewed the outcomes and differences between the transurethral and periurethral routes of injection [14]. There were no statistically significant differences in outcome. In a prospective study by Schulz *et al.*, the authors concluded that both periurethral and transurethral methods were comparable [15]. However, the amount of material utilized was much greater in the periurethral group, which would of course drive the expense of the procedure upward.

Ideally, an injection system scope or a female urethroscope should be used for the procedure. After the bladder is drained, the scope is placed mid urethra. Most techniques describe needle placement at 4 and 8 o'clock with a submucosal injection. The trial with Macroplastique (see below) added an injection at the 6 o'clock position. Many patients require additional treatments and various waiting periods are required for each unique agent.

Postoperatively, a small amount of bleeding or bulking agent leakage can be noted for 1–2 days. Retention can occur and should be treated with 24-h catheterization with a small 8–10F Foley or clean intermittent catheter technique. It is usually self-limiting. If prolonged retention is apparent, then a suprapubic tube should be considered to avoid crossing the urethra which has been treated. Moreover, it is not uncommon to have temporary irritative urinary symptoms. Stothers *et al.* reported a 12.6% incidence of *de novo* urge incontinence in a large prospective trial [18].

Materials

The ideal injectable agent primarily should be safe, i.e. biocompatible, nonimmunologic, and hypoallergenic. It should retain its bulking characteristics for a prolonged interval and not biodegrade or migrate, but it should also be easily explanted or degraded if necessary. Additionally, it should be easy to prepare and implant.

Glutaraldeyde cross-linked bovine collagen

Of the many options, glutaraldehyde cross-linked bovine collagen (Contigen™) is the most studied and used bulking agent. It is a highly purified suspension of bovine collagen in normal saline containing 95% type 1 collagen and 5% type 3 collagen cross-linked with glutaraldehyde for stability, durability, and reduction in hypersensitivity. A skin test is required prior to injection and a recommended 30 days must pass before treatment. The procedure is simple and easy, and in our hands almost exclusively done in the office. It can be relatively expensive over time however, and at least one analysis by Berman and Kreder suggested an uncomplicated sling is more cost-effective [19]. Early results showed promise with very high cure and improvement rates [11], but enthusiasm has been tempered by long-term cure rates of 14–25% and improvement rates of 25–60% [20]. Complications have been divided into early and late [18]. The most common are urgency, transient retention, and hematuria, all usually self-limiting. Other late complications have included delayed skin reactions, particularly with reintroduction of collagen, and arthralgia. Serious complications, such as pulmonary emboli and osteitis pubis have also been reported [21, 22]. The possibility exists for an allergic response to the bovine protein, since a sensitizing pretreatment skin test is performed, although this is reduced by cross-linking. A very small number of patients will have a positive skin test, precluding them from treatment with this agent. The material, however, remains the most widely used injectable for SUI in the world.

Carbon-coated zirconium beads

Carbon-coated zirconium beads (Durasphere™) is a sterile, nonpyrogenic injectable bulking material composed of pyrolytic carbon-coated graphite beads suspended in a 97% water, 3% beta-glucan carrier gel. It is inert and nonimmunogenic, and therefore does not require skin testing.

In a head-to-head trial, Durasphere and collagen were randomized to similar patients. The Durasphere group showed an improvement of 1 or more Stamey grades in 80% of patients compared to 69% in the collagen group. While substantial on the surface, the difference did not meet statistical significance [23].

Recently re-engineered via its carrying gel for delivery, it is now available as Durasphere EXP and has an optimized bead size of 90–212 µm (it is known that macrophages can phagocytize particles of less than 80 µm). Once in this system, the beads theoretically can be transported throughout the body. Durasphere beads should not migrate because of their size. It is possible that the zurconium beads found in lymphatics and other places most often result from high pressure injection. Durasphere is safe and has no risk of allergy. Results have been comparable to those with collagen, but the immediate complications with it are slightly higher, as reflected in the rate of urinary retention, but this rarely persists or needs surgical intervention [24].

Silicone polymers

Silicone (Microimplants, Macroplastique, and Bioplastique) is a soft, flexible irregular material made of vulcanized polydimethylsiloxane macroparticles or simple silicone rubber. The silicone particles are inert, biocompatible, nonbiodegradeable, and nontetratogenic. The mean particle size is 100–300 µm, limiting the chances of migration. The material, however, still must be injected with a special injection system because of its high viscosity. The material was recently approved by the FDA for treatment in SUI.

Reported cure and improvements rates are 60% and 80%, respectively [25, 26]. Complications are similar to those with other agents and include transient hematuria, retention, and UTI. Barrett and others have expressed concern about small particle migration, but this is certainly not common [27].

In a multicenter randomized trial between Macroplastique and collagen, 61.5% of the former agent improved by 1 or more Stamey grades, as opposed to 48% of the collagen group. A total of 36.9% of patients in the Macroplastique group were dry compared with 24.8% of the collagen patients [28].

Calcium hydroxyapatite

Calcium hydroxyapatite (Coaptite) is a synthetic injectable implant composed of smooth calcium hydroxylapatite bioceramic microspheres that have a diameter range of 75–125 µm, suspended in an aqueous gel carrier. A normal constituent of bone, it is also nonimmunogenic, and was previously used in dental and orthopedic surgery. A 12-month prospective, randomized, comparative, multicenter, single-blind, parallel, clinical trial of calcium hydroxyapatite and collagen for soft tissue augmentation of the urethral sphincter in the treatment of SUI enrolled 296 women. Essentially comparable results, 63% and 57% improvement, respectively, were reported. Approved by the FDA in November of 2005, it is used for the treatment of ISD. As yet, at least two serious side effects have occurred: one erosion through the vaginal wall and one injection which dissected into the bladder, causing a tissue bridge to form. Lastly, urethral prolapse has been reported in a delayed fashion months after injection [29].

Ethylene vinyl alcohol copolymer

Initially approved by the FDA in 2004, this injectable was composed of ethylene vinyl alcohol (EVOH) copolymer in dimethyl sulfoxide (DMSO) as a permanent hypoallergenic implant. The material would expand after injection into the urethra, where the DMSO would diffuse out, allowing the EVOH to precipitate as a hydrophilic material. Unfortunately, many patients had dysuria and other complications.

A large multicenter trial was reported by Dmochowski *et al*. with encouraging early results [30]. However, the complications of dysuria and pain later developed into erosions and inflammation often necessitating surgical correction [31]. More recently, experience of the use of EVOH copolymer (Uryx/Tegress) came to a halt because of serious adverse events reported to the FDA. The injectable material previously used to inject arteriovenous malformations was withdrawn from the market in December of 2006, just 2 years after its introduction.

Polyacrylamide hydrogel

Bulkamid urethral bulking agent is a cross-linked synthetic polymer. The peculiarity of this agent is that it is homogeneous as it does not contain any particles. In the original clinical trial on the use of this agent by Lose *et al*., eight patients (38%) were subjectively dry and a further nine (43%) improved. Objectively, urine leakage/24 h decreased by 93% and the number of incontinence episodes decreased by 87% [32]. Quality-of-life measures improved significantly in all domains other than general health perception. There were no significant changes in urodynamic variables. Treatment-related adverse events were recorded in 16 women. Urinary tract infection (UTI; 10 cases) and urinary retention (five cases) were the most common.

Other agents

There have been attempts to use other materials, including dermal collagen implants, autologous fat, and even autologous chondrocytes [33].

Outcomes

Generally speaking, one of the main goals of bulking is to increase the quality of life of patients. A literature review by Chapple *et al*. concluded that quality-of-life improvement after urethral injections appears to be significant and is comparable to that obtained with surgery, despite the observation of superior objective surgical efficacy [34]. The outcomes and adverse effects for each specific material are summarized in Table 141.1.

Table 141.1 Reported (A) adverse events and (B) outcome with bulking agents.

A

	FDA approval	Number of adverse events	Ongoing sales
Contigen	Sept 1993	114	Yes
Coaptite	Nov 2005	3	Yes
Silicone	Dec 2006	–	Yes
Durasphere	Sept 1999	7	Yes
Tegress/Uryx	Dec 2004	201	No

B

Material	Product	Number of reported studies with >50 patients in the last 3 years	Dry or improved (average %)
Collagen	Contigen	15	63
Carbon bead	Durasphere	6	60
Silicone	Macroplastique	8	58
Calcium hydroxyapatite	Coaptite	4	50
Other		3	60
Ethylene vinyl alcohol	Tegress	2	55
Polyacrylamide hydrogel	Bulkamid	3	58

A recent systematic review of randomized trials for noninvasive anti-incontinence procedures included seven randomized controlled trials (RCTs) on a total of 882 women implanted with different injectable bulking agents [35]. The level of evidence was classified as low. Rates of continence and improvement were similar among the different agents in most of the RCTs. Curative effects were shown after intraurethral collagen injection in women with SUI (51.5% were dry during a 24-h pad test) [36]. Transurethral injection of a porcine dermal implant resulted in a negative pad test results (i.e. cure) in 60% of women with urodynamically-proven SUI [37]. Transurethral injection of the bulking agent dextran copolymer resulted in objective cure in 15% of women with stress or mixed incontinence (minor and controlled urge component) in whom previous conservative treatments had failed [15]. Only one RCT reported statistically significant relative benefit. This benefit was seen in 63 women with SUI at 12-month follow-up after transurethral ultrasonography-guided injections of autologous myoblasts and fibroblasts, compared with conventional endoscopic injections of collagen (relative risk 9.5, 95% CI 2.53–35.63; risk difference 0.81, 95% CI 0.66–0.96) [38]. (This paper has been recently withdrawn for ethical issues.)

Future agents

The most exciting and promising field may be that of tissue engineering. There have been some successes using autologous myoblasts and fibroblasts for urinary incontinence [39], with three-dimensional ultrasound revealing an increase in the size of the urethra and rhabdosphincter from baseline. However, lately these results have been seriously questioned [40].

Conclusions

The role of urethral bulking agents has evolved over the last two decades in parallel to the developing technology of slings. As a result, they are more frequently used in patients with multiple medical comorbidities whose increased surgical risks prevent them from having open surgery. Moreover, once considered a primary treatment, today these agents are best used as an adjunct to a failed sling or other anti-incontinence surgery. The search for a more perfect injectable agent continues as the fields of biomaterials and regenerative medicine now look to better understand SUI.

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CHAPTER 142

Single-Incision Slings

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Introduction

Stress urinary incontinence (SUI) as defined by the Standardization Sub-Committee of the International Continence Society is the complaint of involuntary leakage of urine with effort, exertion, sneezing, or coughing [1]. It is estimated to affect approximately 25% of women in the USA between the ages of 30 and 60, and surgical therapy has been the mainstay treatment for the last 100 years. Anti-incontinence procedures initially emerged in the form of pubovaginal slings, Burch colposuspensions, and bladder neck suspensions. However, over the last 10 years, minimally invasive synthetic sling procedures have been developed and modified, and now predominate [2–4].

This transition began in the 1990s when Ulmsten and Petros described the integral theory [5]. This theory suggests that a weak pubourethral ligament causes inactivation of the muscle forces that contribute to urethral and bladder neck closure in the regulation of continence. They then demonstrated that a damaged or lax ligament is unable to be tightened effectively with sutures, but could be supported at the mid urethra with an artificial neoligament. Thus, they introduced the first tension-free polypropylene mesh sling to support the mid urethra. It successfully provided continence by reinforcing the pubourethral ligaments with a midurethral tape that was anchored retropubically [5, 6]. The benefits of this new methodology included acceptable cure rates with lower morbidity than found in previous procedures [6].

Since the landmark hypothesis of Ulmsten and Petros, there has been a steady evolution of pubovaginal slings, from retropubic to transobturator, and now single-incision slings. Each subsequent sling has been developed to decrease the unexpected morbidity found with its predecessor, while striving to retain the 82–95% cure rates seen at 1 year with the “gold standard” Burch procedure [2].

Pubovaginal slings

Retropubic polypropylene tape sling

Ulmsten and Petros developed tension-free vaginal tape (TVT), the first minimally invasive retropubic polypropylene tape (RPT) sling procedure performed under local anesthesia for SUI. Their novel procedure begins with injection of local anesthetic abdominally and vaginally along bilateral trocar paths. Through a 1.5-cm vaginal incision, bilateral periurethral dissection is performed to the inferior aspect of the pubic bone. Trocar needles with attached prolene mesh tape, covered by a plastic sheath, are inserted into the vaginal incision and then passed through the urogenital diaphragm, into the retropubic space just deep to the pubic bone and then out through the suprapubic area. Cystoscopy is then routinely performed to rule out any bladder perforations. After the tape is adjusted with a cough test to insure continence, the plastic sheath is removed and incisions are closed [5, 6].

Initial 3-year data demonstrated that this new RPT sling resulted in 86% cure rates and 11% improvement rates [6]. Long-term results observed by Nilsson *et al.* over an 11.5-year period also confirmed subjective cure

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Table 142.1 Mid-urethral slings.

	Manufacture	Approach	Date
Retropubic			
TVT	Ethicon Women's Health	Transvaginal	1998
SPARC	American Medical Systems	Suprapubic	2001
TVT with abdominal guides	Ethicon Women's Health	Suprapubic	2002
Advantage	Boston Scientific	Transvaginal	2003
Lynx	Boston Scientific	Suprapubic	2004
Supris-SP	Coloplast	Suprapubic	2006
Align-RP	Bard Urologic	Transvaginal	2007
Align-SP	Bard Urologic	Suprapubic	2007
Transobturator			
Monarc	American Medical Systems	Outside–In	2002
ObTryx	Boston Scientific	Outside–In	2004
TVT-O	Ethicon Women's Health	Inside–Out	2004
Aris	Coloplast	Outside–In	2005
Align-TO	Bard Urologic	Outside–In	2007
Single incision			
TVT-Secur	Ethicon Women's Health	Vaginal	2006
Needleless System	Neomedic International	Vaginal	2007
MiniArc	American Medical Systems	Vaginal	2007
Solyx SIS System	Boston Scientific	Vaginal	2008
Ajust	Bard Urologic	Vaginal	2009

rates of 77% and improvement rates of 20% [7]. Randomized controlled trial evidence suggests that TVT has a similar cure rate to colposuspension [8, 9]. Since 1998, several RPT slings have been marketed as either transvaginal or suprapubic needle insertion techniques (Table 142.1). Many of these RPT slings have not yet been adequately tested in observational or comparative trials.

Although the overall efficacy of RPT slings was encouraging, the blind passage of trocar needles into the retropubic space created a new set of potential complications. A review by Atherton *et al*. showed that RPT procedures are associated with a 0.2–1% postoperative urinary retention rate, a 3–4% risk of bladder, urethral or intestinal perforation, and a 1–2.5% risk of major vessel and nerve injury and hematoma in the retropubic space [10]. These complications, although infrequent, lead to further modifications and improvements in minimally invasive urinary incontinence surgery.

Transobturator polypropylene tape sling

In an attempt to avoid rare, but unwanted, complications associated with the retropubic trocar needle passage, Delorme explored the transobturator approach to polypropylene sling placement in 2002. Through an "outside–in" transobturator approach, the trocar needles could be placed at a safe distance from the retropubic blood vessels and viscera, while maintaining proper mid-urethral support [11]. Transobturator tape (TOT) slings involve insertion of trocars around the ishiopubic ramus through the obturator membrane and out through a 1.5-cm midline vaginal incision. After loading the tape onto the trocar, the sling is positioned for mid-urethral support. In 2004, De Leval reported an "inside–out" TOT procedure [12]. In a similar fashion the polypropylene tape was positioned from mid urethra to obturator space, but the trocar was passed from the urethral incision to the groin incision.

Since 2002, several TOT slings have been marketed as either "inside–out" or "outside–in" approaches (Table 142.2). TOT sling cure or improvement rates have been shown to be 90% effective for both these approaches, rates that are comparable to the RPT sling [13–15]. In support of the transobturator method, several studies found the new TOT technique to be equally as efficacious as RPT slings [16–20]. Compared to retropubic slings, the TOT procedure demonstrates minimal risk of bladder perforation and bowel injury; however, there have been reports of subjective groin pain, possibly related to obturator nerve compression or muscle irritation [20]. *De novo* urgency rates appear to be less after a TOT compared to a RPT sling. Botros *et al*. found decreased *de novo* urgency rate with TOT: 8% for TOT versus 33% for transvaginal RPT and 17% for suprapubic RPT [21].

Single incision sling

Soon after the introduction of the TOT slings, engineers began designing the next generation of mid-urethral slings; the single-incision sling (SIS). Building on the RPT and TOT platform of efficacy and ease of use, the SIS was designed to potentially avoid the need for the mesh to transverse any major muscles, reduce risk of organ injury and procedure time, and hopefully achieve a better patient experience (i.e. no external incisions, local anesthesia, minimum postoperative pain, and office-based therapy) [22, 23]. Because of the success of RPT and TOT, the first SIS was designed to be placed

Table 142.2 Single incision slings.

	TVT Secur™ System	MiniArc™	Solyx™ SIS System	Needleless® System	Ajust™
Needle	Two needles and needle driver	One needle with driver	One needle with driver	None	One needle with driver
Needle diameter (mm)	8.1	2.3	3.81	–	5
Size (cm)	1.1 × 8	1.1 × 8.5	9	1.4 × 12	
Fixation	Absorbable 2-cm tips coated with polyglactin and poly-p-dioxanone	Permanent self-fixating tips	Permanent polypropylene mesh carriers	Lateral pocket positioning system	Permanent self-fixating polypropylene anchors
Laser cut	Yes	N/A	Heat sealed, detanged	Yes	Die cut
Fixation location	Obturator internus muscle/ inferior ischiopubic ramus or urogenital diaphragm/pubic bone	Obturator internus muscle	Obturator internus muscle	Through fascia of internal obturator muscle	Obturator membrane
Trajectory pathway	Transobturator or Retropubic	Transobturator	Transobturator	Transobturator	Transobturator
Intraoperative tightening	By advancing only, none after device is released	Yes, optional redocking feature	By advancing only, none after device is released	None	Yes
Midline mark	No	Yes	No	Yes	Yes
Needle disengagement	Two- step process	One step	One step	None	One step
Pull out force (lb)	1.9	5.5	4.64	1.9	6.56

either in the retropubic or transobturator pathway. Early results were mixed and not consistently reproducible due to multiple factors, including fixation technique, surgeon learning curve, and appropriate tensioning techniques [24, 25]. Since their first introduction in 2006, several SISs have emerged. Each SIS is made of type 1 polypropylene, but has a unique sling length, trajectory pathway, delivery device, fixation method, and fixation location (see Table 142.2).

Although the selection of patients for SIS is evolving; most surgeons reserve SIS for SUI patients without prior anti-incontinence surgery. As with RPT and TOT slings, SIS procedures are contraindicated for the following patients: pregnant or planning a pregnancy in the future, or with blood coagulation disorders, compromised immune system, renal insufficiency, and urinary tract obstruction or infection.

Early data are promising that these new SISs can provide successful mid-urethral support with less dissection, shorter procedure time, and less attendant morbidity of leg muscle or obturator nerve adverse events [25–27] (see also Table 143.2, summarizing results).

TVT-Secur System

In 2006, the SIS generation began with the introduction of the Tension-Free Vaginal Tape-Secur™ (Ethicon Women's Health & Urology, Somerville, NJ, USA). TVT-Secur measures 8.0 × 1.1 cm and utilizes the same proprietary macroporous polypropylene fiber used in Ethicon's RPT and TOT slings (Figure 142.1). Besides the shorter length, TVT-Secur's other unique properties include: laser cut mesh, absorbable fixation tips, and multiple placement approaches. Unlike the tanged mesh edges, laser cut mesh edges offer the benefits of consistent width and minimal stretch to facilitate proper placement. The innovative 2-cm absorbable fixation tips made of polyglactin 910 (Vicryl) and poly-p-dioxanone (PDS) provide immediate mechanical fixation which, over roughly 3 months, is replaced by tissue ingrowth. TVT-Secur fixation demonstrates strength over time with initial animal mean pull-out force of 864 g (vs 771 g for the original TVT) that increases to 6509 g at 12 weeks [28]. The versatile design of the TVT-Secur allows placement in either the "U" retropubic trajectory position or

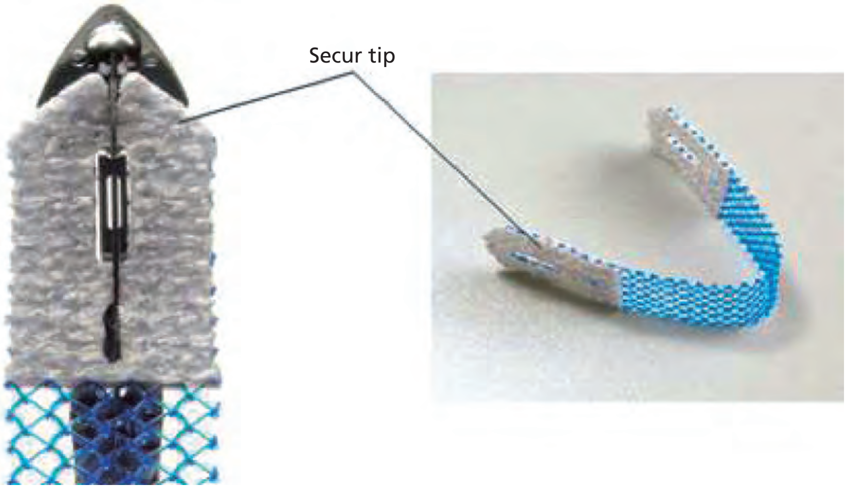

Figure 142.1 TVT Secur System. TVT-Secur laser-cut mesh edges with the 2-cm absorbable fixation tips (reproduced by permission of Ethicon Women's Health & Urology, Somerville, NJ, USA).

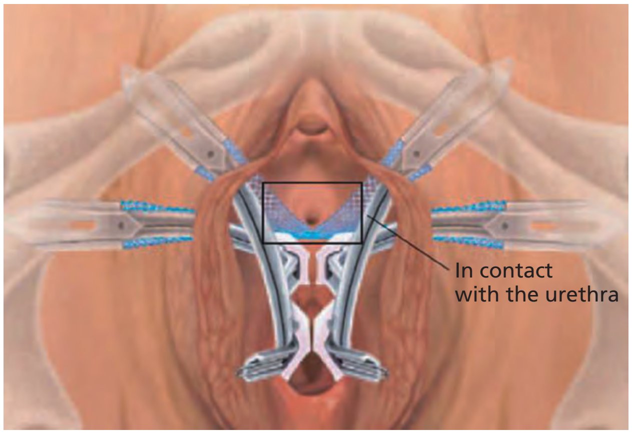

Figure 142.2 TVT-Secur placement. TVT-Secur can be placed in either the "U" retropubic trajectory position or the "hammock" transobturator trajectory position. (reproduced by permission of Ethicon Women's Health & Urology, Somerville, NJ, USA).

the "hammock" transobturator trajectory position [25–27] (Figure 142.2). The "U" configuration mimics the RPT placement with the fixation tips placed into the connective tissue of the urogenital diaphragm against the periostium on the pubic bone. The hammock position imitates the TOT trajectory and the absorbable fixation tips anchor into the muscle complex of obturator internus muscle against the posterior edge of the inferior ischiopubic ramus [29]. As the procedure evolved, it became evident that the fixation tips must remain in contact with the respective bony structures in order to maintain stable long-term fixation. Stabilizing the fixation tips to mobile muscular structures alone proved to provide less than satisfactory results [3].

Procedure

After local infiltration, a 1.5-cm mid-urethral incision is made in the anterior vaginal wall [29]. The vaginal and paraurethral incision should be made slightly larger than with conventional slings in order to accommodate the TVT-Secur device. To avoid dragging paravaginal tissue during insertion, the paraurethral dissection for both the "U" and "hammock" must maintain its initial width.

TVT-Secur "U"

Similar to RPT placement, the dissection is performed to the inferior edge of the pubic bone. The urogenital diaphragm should not be penetrated by the scissors, as this will reduce the holding ability of the fixation tips. Before placing the TVT-Secur, a urethral catheter with guide should be placed to minimize injury to the lower urinary tract by the TVT-S inserter. The TVT-S is placed flat to and in contact with the back of the pubic bone, while being pushed into the dense connective tissue of the urogenital diaphragm and aimed towards the ipsilateral shoulder. Close contact with the pubic bone assures correct placement. The procedure is repeated on the contralateral side.

TVT-Secur "hammock"

Similar to TOT placement, the dissection is performed laterally to the lower edge of the ischiopubic ramus. The obturator internus muscle should not be penetrated by the scissors, as this may reduce the holding ability of the fixation tips. The TVT-S is placed flat to and in contact with the lower edge of the ischiopubic ramus, while being pushed into the obturator internus muscle. The inserter blade must always stay in contact with the bony surface to achieve long-term fixation. The procedure is repeated on the contralateral side. Proper mesh tension can be achieved with bilateral incremental advancement of the device. Optimal results may not be achieved if the placement is complicated by rotating movements, tearing of the obturator muscle, or placing the device away from the bony pelvis.

Tensioning

Proper device tensioning is essential to successful placement in the "U" or "hammock" position (see Videos 142.1A and 142.1B, respectively). Unlike traditional midurethral slings that are pulled into place, the tension of the TVT-Secur single-incision sling will not increase postoperatively. Tensioning options include dynamic cough/Crede stress test or visual assessment, making sure that the sling is flush with the urethra, causing a pillowing effect (filling of the tape pores with suburethral tissue) [29]. Adjustments in tensioning can only be done with the inserters in place and, once the release wires are pulled, it is not possible to reconnect for further adjustments. Cystoscopy may be performed at the physician's discretion and the incisions are closed according to usual method.

Results

There are several short-term reports of TVT-Secur in the literature; however, very few trials of longer than 1 year have been published. Several of the initial reports of TVT-Secur demonstrated unfavorable outcomes with poor success rates ranging from 67% to 83%, much lower than with the existing traditional RPT and TOT slings [24, 30, 31]. Many authors noted a significant learning curve in the adoption of the TVT-Secur. Improper sling tensioning and not placing the fixation tip against the pubic bone or ischiopubic ramus resulted in device dislocation and immediate or recurring SUI. As experience has evolved and techniques have been refined, long-term studies have demonstrated more consistent results. Procedural modification reported by Neuman *et al*. in their prospective trial of 100 women demonstrated improved success rates and decreased morbidity [29]. By placing the TVT-Secur tape flush to the urethra without space between the tissue and mesh, the continence rates improved from 88.6% in the first 50 patients to 93.5% in the last 50 patients. Tensioning the sling flush with the urethra did not increase the rate of urinary retention or obstruction. When comparing the first 50 patients to the last 50 patients, experience and meticulous attention to dissection and procedural details resulted in fewer adverse events by elimination of vaginal wall penetration with the inserters (8% vs 0%), decreased unintended tape removal by the inserter (10% vs 0%), and fewer tape extrusions (12% vs 8%).

In a prospective multicenter trial evaluating 95 women with urodynamically confirmedSUI, Meshia *et al*. noted a 78% subjective cure rate and 81% objective cure rate (negative cough stress test) with TVT-Secur at 1 year [26]. Although not designed as a comparison trial, there was no difference in success rates for the "U" and "hammock" approaches. Postoperative pain was reported by only one woman. Postoperative complications included voiding difficulty (8%), recurrent urinary tract infection (UTI) (10%), *de novo* urgency incontinence (10%), and dysparunia with mesh protrusion (2%) [32].

Both TVT-Secur approaches appear to have comparable effectiveness. In a randomized comparative trial of 115 women, Kim *et al.* reported no statistical difference in cure rate at 12 months based upon the Sandvik questionnaire: [88.7% (47 of 53) U-type and 87.1% (54 of 62) hammock-type approach, $P = .796$) [33]. Both techniques demonstrated equivalent short operative time (14.8 ± 6.3 min for the U-type approach and 13.4 ± 5.1 min for the hammock-type approach, $P = .114$). Immediate postoperative pain as measured by visual analog scale (VAS) was minimal for each approach (2.2 ± 2.0 for the U-type approach and 2.1 ± 1.8 for the hammock-type approach, $P = .926$). There were no severe complications related to either approach; however, vaginal wall perforation occurred with the hammock-type approach and temporary retention occurred in three patients (two U-type approach and one hammock-type approach).

Overall TVT-Secur in its "U" and "hammock" configurations demonstrates effectiveness in treating SUI with minimal morbidity. There appear to be critical technical points to the procedure that can substantially impact a successful outcome. With experience and attention to detail, TVT-Secur can demonstrate acceptable cure rates compared to RPT and TOT; however, comparative trials and long-term follow-up trials are warranted.

MiniArc sling

One year after the introduction of TVT-Secur, the MiniArc™ (American Medical Systems Inc, Minnetonka, MN, USA) was released in the USA and Europe as the second SIS. The MiniArc consists of an 8.5 cm × 1.1 cm polypropylene sling with integrated self-fixating tips that anchor into the obturator internus muscle through a single vaginal incision (Figure 142.3). MiniArc's simplified design and approach capitalized on some of the early design criticisms of the TVT-Secur device. Differential design features include the narrow inserter, self-fixation tips, tanged mesh edges, redocking feature, and insertion into the obturator internus muscle. The

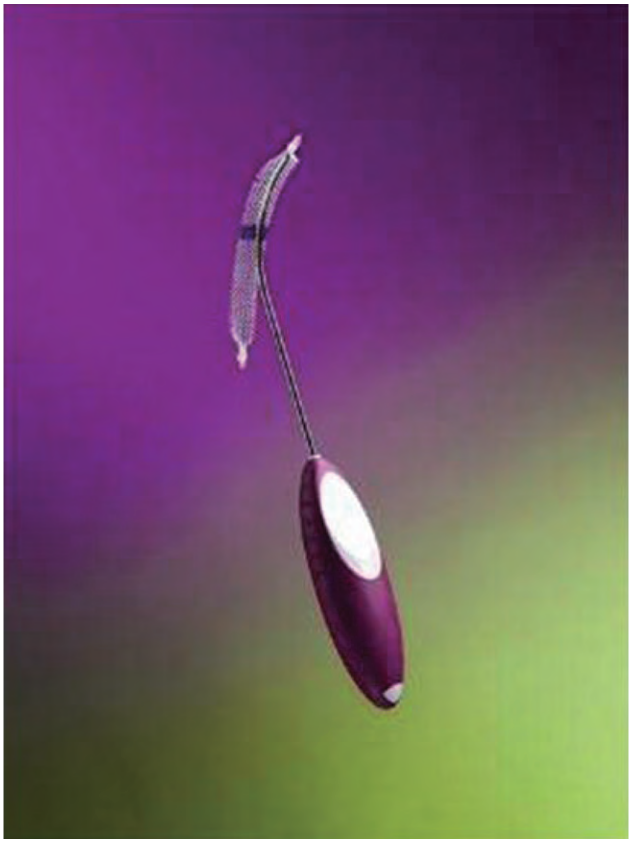

Figure 142.3 MiniArc. The MiniArc's 1.1 × 8.5-cm macroporous polypropylene mesh fused to self-fixating tips is placed with a 2.3-mm needle (reproduced by permission of American Medical Systems Inc, Minnetonka, MN, USA).

MiniArc mesh utilizes the same type 1 knitted polypropylene mesh used in American Medical System's RPT and TOT procedures.

The slip-fit mesh-to-needle connection allows easy engagement and disengagement of mesh to needle. Compared to the TVT-Secur, this smooth disengagement feature dramatically lessens the risk of inadvertently moving or loosening the mesh while removing the inserter device. By redocking the needle to the mesh after removal of the inserter, MiniArc's design allows further intraoperative tensioning during placement if desired. With the small 2.3-mm needle diameter, the push-in force required to deliver the MiniArc (2.56 lb) was less than that for the TVT-Secur (4.52 lb) (data on file, American Medical Systems). The polypropylene permanent self-fixation tips were designed to provide short-term holding force that prevents migration during initial tissue ingrowth. Compared to a pelvic floor event at a force of 1.3 lb, cadaver bench testing showed that 5.5 lb of pull-out force is required to remove the MiniArc [34, 35]. Despite these design features, skepticism regarding adoption of MiniArc SIS centers around the initial and long-term fixation strength of the obturator internus muscle and proper tensioning techniques.

Procedure

Similar to other SIS procedures, a 1.5-cm vaginal incision is made at the level of the mid urethra. Bilateral periurethral tissue dissection is performed toward the interior portion of the inferior pubic ramus. The sling/needle assembly is guided along the posterior surface of the ischiopubic ramus in a transobturator trajectory towards the obturator space bilaterally. Once the integrated sling tip is fixed into the obturator internus muscle, the needle is then removed and the procedure repeated on the contralateral side. Upon sling placement, further tension can be delivered by using a redocking feature that provides access to the implanted tip placed on the initial side. The mesh should lie flat against the urethra without any mesh distortion or space between the urethra and sling. Dynamic stress testing (cough stress test/Valsalva test) or visual inspection aids in proper sling tensioning. Cystoscopy may be performed at the surgeon's discretion and the vaginal incision is closed [36, 37] (see Video 142.2).

Results

Several promising results have been reported with the MiniArc SIS. Early clinical reports indicate a shortened procedure time (<10 min), minimal blood loss, quick learning curve, and ability to perform the procedure under local anesthesia [36–38]. There is a paucity of long-term studies; however, all of those to date support the safety of this minimally invasive procedure with efficacy rates that are similar to those for RPT and TOT.

A small study by Palma *et al*. reported an 88% cure rate in 18 patients at 12 months [39]. In 2009, Moore *et al*. reported 1-year retrospective data evaluating the first 61 patients with MiniArc. The procedure time was 7 min (±3.3 min) and estimated blood loss was 27 mL (± 16 mL). Consistent with previous studies, they had an overall cure rate of 91.4% and no adverse complications, including no intraoperative complications, pain, dyspareunia, or sling erosion [38]. The first prospective multicenter international trial was recently published by Kennelly *et al.*, with 157 of the 188 women enrolled available for follow up at 1 year. Based upon procedural data, the MiniArc was minimally invasive with a quick procedure time (mean 11.0 min), minimal estimated blood loss (mean 41.7 mL), short length of hospital stay (mean 9.5 h), and minimal discomfort post procedure (mean pain score 1.3). At 1-year follow-up, 90.6% of patients had a negative cough stress test and 84.5% had a 1-h pad weight test of less than 1 g. No complications such as injury to bowel, bladder, urethra, blood vessels, abscess or leg neuropathy occurred in this study. Adverse effects are uncommon and likely due to sling placement outside the transobturator space or medial groin muscles [27]. However, Gauruder-Burmester reported that 36.8% of patients developed *de novo* urge incontinence [40]. The placement of self-fixating tips in a tension-free manner is a challenge and depends on factors such as tissue properties, insertion techniques, and tape position/retraction.

Overall, the early MiniArc data regarding efficacy, safety, and patient tolerability is very encouraging. Standardization of tensioning techniques and long-term durability studies will likely foster wider adoption of SIS such as MiniArc.

Solyx

The Solyx™ SIS system (Boston Scientific Corporation, Natick, MA, USA) was introduced in North America in 2009. It consists of a delivery device and a 9-cm mesh assembly with nonabsorbable polypropylene carriers on each end (Figure 142.4). These carrier barbs serve to anchor the sling into the obturator internus muscle while permanent tissue ingrowth occurs over time. The mesh assembly is composed of the same polypropylene mesh used in Boston Scientific's RPT and TOT procedures. The 4-cm central portion of the mesh is heat sealed and detanged to resist deformation and potentially reduce irritation to the anterior urethral wall. The delivery device has a snap-fit on the delivery tip, which is designed to prevent premature carrier slip-off during insertion. In addition, this delivery/carrier attachment allows microadjustability to loosen and tighten the sling prior to releasing the carrier. The tanged lateral mesh portion may allow for minimal loosening and once the carrier is deposited in the obturator internus muscle, it cannot be reconnected onto the delivery device for additional adjustment [25].

Procedure

After local infiltration, a 1.5-cm vaginal incision is made at the level of the mid urethra. Bilateral dissection is performed at a 45° angle toward the inferior pubic ramus, creating a pathway for delivery device placement. The mesh assembly is placed onto the delivery device until it is flush with the end and an audible "click" is heard. The delivery device is inserted and advanced towards the obturator foramen just lateral to the inferior pubic ramus and until the midline mark on the mesh is at the mid urethra. The mesh carrier is released into the surrounding obturator internus muscle tissue by holding the deployment mechanism with one hand and pulling the delivery device handle with the other. The delivery device is removed from the incision and the second mesh assembly is placed on the delivery device and contralateral side placement is repeated. Tensioning options include a cough stress test and visual assessment to ensure the sling is positioned against the urethra (allowing a small enough space to place a small instrument or

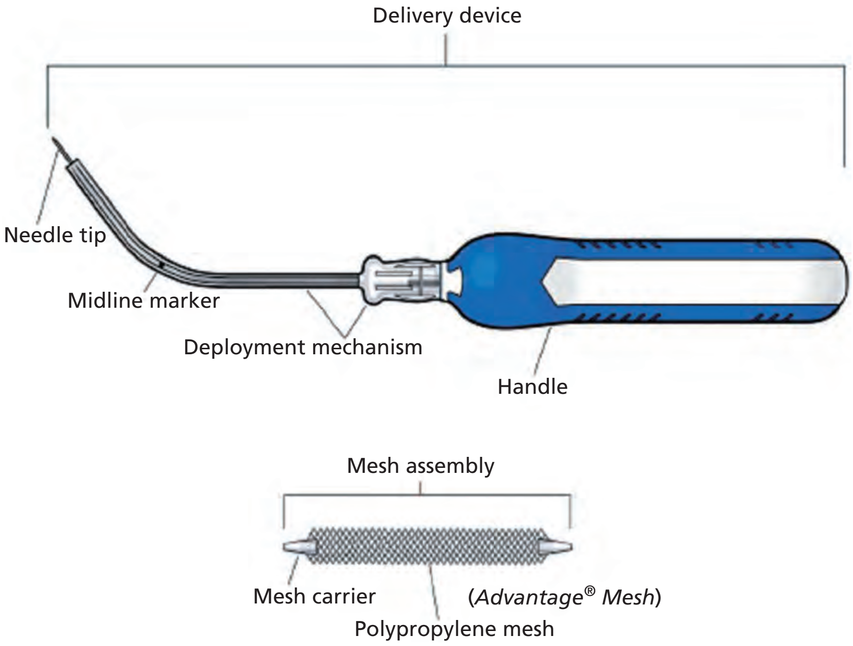

Figure 142.4 Solyx Single Incision Sling System. The 9.0-cm polypropylene sling consists of a mesh assembly with carriers fixed to the ends. The delivery device has a handle, needle tip, and midline marker (reproduced by permission of Boston Scientific Corporation, Natick, MA, USA).

checking that the periurethral tissue "pillows" through the pores in the mesh). With the delivery device still attached to the mesh assembly, modest advances and retreats can be made to tighten or loosen the sling as needed to achieve the desired tension. However, it is important to note that once a carrier is deposited into the tissue, it is not possible to reconnect it for further adjustments [25]. Cystoscopy may be performed at the physician's discretion and the incisions are closed according to the usual method (see Video 142.3).

Results

There is a paucity of peer-reviewed data on Solyx, mainly due to its recent introduction in 2009. In a retrospective review, Serels *et al.* reported their three-center preliminary results for the Solyx SIS system in patients with urethral hypermobility (q-tip > 30°); 59% of patients had concomitant repairs [25]. At a mean follow-up of 6.5 months (range 5–8 months), 95% (60 of 63) were dry both by subjective patient assessment (patient states they are completely dry) and objective physician assessment (negative standardized cough stress test). Only two of 63 patients had transient urinary retention and there were no adverse events of bladder, bowel, vessel or nerve perforations, and no erosions, extrusions, muscle or groin pain. This short-term, prospective analysis provides encouraging data that will need to be confirmed in larger, prospective studies with longer follow-up.

Needleless

The Needleless® System (Neomedic International, Terrasa, Spain) quietly emerged from Europe in 2007. It consists of a 12 cm × 1.4 cm macroporous monofilament polypropylene mesh with a blue midline suture (Figure 142.5). Unique to this device is the lack of inserter needle or anchor system. The patented lateral pocket positioning system provides the initial holding strength in the obturator internus muscle. With only 16% less surface area for tissue ingrowth than a traditional TOT sling, the Needleless sling hopes to offer the same clinical benefits of a TOT sling through a single vaginal incision [41]. Additionally, no sharp introducer needles are required to implant the sling, which enhances patient comfort and is fundamentally attractive for local anesthesia.

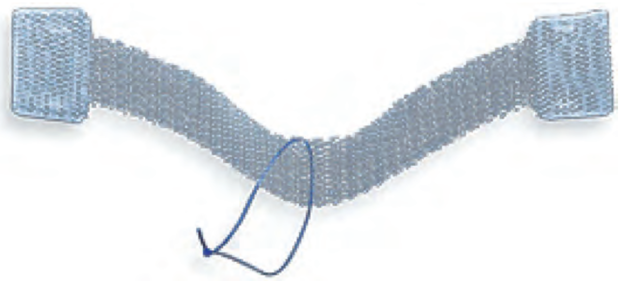

Figure 142.5 Needleless System. The needleless sling has a patented lateral pocket positioning system. The midline blue suture can be removed intraoperatively or left in place for post operative adjustments (reproduced by permission of Neomedic International, Terrasa, Spain).

Procedure

After local infiltration, a 2-cm incision is made at the mid urethra on the anterior vaginal wall. A horizontal submucosal tunnel is dissected to the edge of the ischiopubic ramus. The Needleless sling is prepared by introducing a surgical forceps (i.e. tonsil) in one of the terminal pockets of the sling. The forceps are inserted into the pocket of the sling, and the pocket is folded between the jaws of the forceps. The folded pockets are introduced through the dissected spaces directed at approximately 30° from the midline. The Needleless mesh pockets should be guided to the 10 o'clock and 2 o'clock position respectively, relative to the urethra. The surgical forceps and mesh sling are pushed into the obturator internus muscle to the point that the central sling traction thread is within 1 cm from the urethral midline. Release of the sling is accomplished by opening the forceps, extending the sling pocket positioning/anchoring system, and then carefully closing and removing the forceps. The process is then repeated on the contralateral side. The sling is placed flush with the urethra while counter-traction is used on the central thread to aid in centering the sling. Intraoperative adjustments of the sling can be made by reinserting the forceps into the pockets on either side and advancing the sling further into the muscle. Cystoscopy may be performed at the physician's discretion and the incisions are closed according to the usual method. The traction thread should be cut off, although it may be left in place for a maximum of 48 h, and can be used to loosen the mesh in the case of postoperative urinary retention [41] (see Video 142.4).

Results

Despite being developed in 2007, scant peer-reviewed literature is available for the Needleless sling. Navazo *et al.* reported their preliminary experience with their first 120 patients undergoing the Needleless procedure [41]. All patients had urodynamically confirmed SUI and 83% (100 of 120) had concomitant repairs. The mean procedure time was 10 min (range 5–1 5 min). Based upon a negative cough test, 100 patients (84%) were objectively cured, 10 (8%) improved their incontinence, and 10 (8%) were considered failures. This series did not report any cases of inguinal pain, hemorrhage, hematoma, vascular or visceral damage; however, there was one sling extrusion managed successfully with estrogen cream.

Over the years, several Needleless abstracts have been presented at various international society meetings. Beya *et al*. reported 1-year follow-up in a prospective multicenter study of 78 patients with SUI [42]. Mean operative time was 7 min (range 4–20 min) and hospital stay was 8 h (range 4–24 h). Based upon objective and subjective measures, 69 patients (88%) achieved cure of stress incontinence, four (5%) improved, and six (7%) failed. There were no immediate complications; however, four partial erosions (5%) were successfully managed with local estrogen therapy. Two patients had *de novo* urge incontinence and three had urge urinary incontinence managed with antimuscarinic agents.

Another Spanish multicenter trial involving 230 females with SUI was presented in 2008 [43]. All patients had urethral hypermobility and patients with neurogenic incontinence or intrinsic sphincter deficiency were excluded. The mean age was 51 years (41–70 years) and mean operative time 9 min (range 7–14 min). After a mean follow-up period of 12 month, 198 patients (86%) were objectively cured of SUI, 14 (6%) improved, and 18 (8%) failed based upon cough stress test. Complications included five temporary retentions, two nonintervention hematomas, and two partial sling extrusions treated with local estrogen therapy.

Initial reports of the Needleless procedure are encouraging. Further multicenter studies with longer follow-up need to be published to confirm the long-term effectiveness of this technique.

Ajust

The Ajust™ Adjustable Single-Incision Sling System (CR Bard Inc, Murray Hill, NJ, USA) was introduced in Europe in 2008 and North America in 2009. It was designed to offer all the benefits of a TOT sling procedure through just one vaginal incision. The Ajust sling system includes: a fully adjustable sling with self-fixating polypropylene anchors; an introducer designed to place the sling in the obturator membrane; and a flexible stylet used to lock the sling after adjustment (Figure 142.6). Unlike other SISs, the Ajust sling is placed through the obturator membrane, mimicking a traditional TOT sling placement. This new sling utilizes the obturator membrane fixation through a single-incision approach versus the three-incision pull-through approach of traditional TOT slings. For most single-incision slings, adjustment is dependent upon manipulating the introducer/needle mechanism and postinsertion adjustment is not feasible. The Ajust polypropylene mesh sling features two anchors, one fixed and one adjustable, and is constructed with a suburethral section, as well as a tubular adjustment mesh that slides in either direction through the anchor. These mesh design features allow bidirectional independent adjustment (tightening and loosening) of the sling mesh relative to the anchors without visual obstruction from the introducer in the surgical field. After optimal sling tension setting, the flexible stylet is utilized to lock the sling into place.

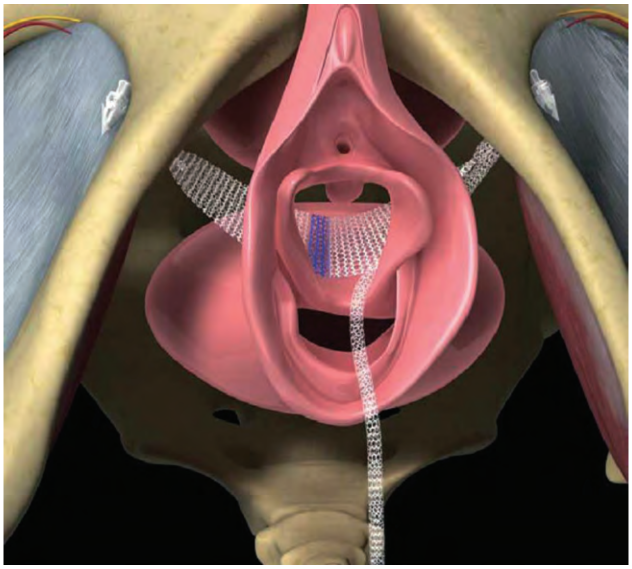

Figure 142.6 Ajust Adjustable Single-Incision Sling. The Ajust is placed through the obturator membrane with self-fixating anchors. Postinsertion adjustments can be made by loosening or tightening the mesh relative to the fixed anchors (reproduced by permission of CR Bard Inc, Murray Hill, NJ, USA).

Procedure

After local infiltration, a 1.5-cm incision is made at the mid-urethral level on the anterior vaginal wall, and a horizontal tunnel is created up to the edge of the ischiopubic ramus. The device is then inserted horizontally towards the cephalad margin of the ischiopubic ramus, and pushed straight into the obturator internus muscle. Once the fixed anchor passes the ischiopubic ramus, the surgeon must pause from the original push while pivoting the introducer handle past the midline, and then resume a second straight push maneuver to place the anchor completely through the obturator muscle and membrane. The midline indicator must be deviated past the midline toward the fixed anchor side to confirm proper depth of placement. The fixed anchor is then released and traction is applied to the suburethral portion of the sling to confirm proper anchor engagement. The adjustable anchor is then loaded into the introducer and the steps are repeated on the opposite side. Once the adjustable anchor is correctly placed, the adjustment tab and tubular mesh is then pulled until the surgeon achieves the desired "set-point" of the suburethral sling. Once optimal setting has been achieved, the flexible stylet is used to advance the sling lock into the adjustable anchor, locking it in place. The system is designed to permit post-anchor insertion bi-directional tension adjustability (loosening and tightening) after the sling implantation without further insertion of the introducer. Cystoscopy may be performed at the physician's discretion and the vaginal incision is closed according to the usual method (see Video 142.4).

Results

There are no peer-reviewed reports of the experience of Ajust to date; however, several abstracts have been presented at international meetings. Naumann *et al.* reported their four-center prospective observational study on their first 30 patients of whom nine had previously failed SUI therapies in 2009 [44]. Nearly 50% of the surgeries were done under local anesthesia and no concomitant prolapse surgery was performed. All procedures were done in under 15 min without any intra- or post-operative complications. At a mean follow-up of 3 months, all 30 patients were dry based upon clinical examination, although one patient experienced mild urgency. There were no cases of dysparunia or other pain at 3 months based upon VAS scores.

At the International Continence Society meeting in 2010, Naumann *et al.* presented the multicenter 1-year follow-up on their first 52 patients [45]. All but one of the procedures were completed in less than 30 min and 98% of the Ajust implants were successful (one case converted to a TOT), but one case was removed after 2 weeks due to dislocation. At 1-year follow-up, 45 patients demonstrated total restoration (86.5%) of their continence, one demonstrated improvement (1.9%), and five failed (9.6%) based upon a standardized stress test. There were no cases of dysparunia or other pain at 12 months based upon VAS scores.

At the same meeting, Lucente *et al.* reported on a single French center prospective observational study in 43 patients [46]. Forty patients received local anesthesia and were managed on an outpatient basis, whereas three patients had general anesthesia and were hospitalized for 24 h. The mean operative time was 14.9 min (range 10–15 min). One patient had a postoperative vaginal bleed and one had urinary retention successfully managed with 1-day catheter drainage. At a mean follow-up of 8.4 months (range 4–14 months), 91% (39 of 43) wore no pads, had a negative cough stress test, and were fully satisfied based on validated patient global impression of improvement scale.

Overall, the various preliminary reports of the Ajust sling have demonstrated its short-term effectiveness in treating genuineSUI, with limited and mild complications or adverse events. The anchoring into the obturator membrane with bi-directional adjustability appears to have very good initial subjective and objective success rates. Further prospective studies with longer follow-up are needed to prove the sustained durability and efficacy.

Conclusions

SUI is debilitating and treatable with surgical interventions. Excellent success rates have been reported with both the RPT and TOT slings; however, both approaches require blind passage of trocars that risks visceral and vascular damage. Since 2006, SISs have been used in an attempt to decrease the morbidity associated with the minimally invasive approach. However, these procedures must be approached with caution and providers must understand that minimally invasive slings are not simpler, but require much attention and detailed dissection. It is anticipated that decreased complications, high continence rates, and ease of application under local anesthesia may eventually allow SISs to become an office procedure. The encouraging initial results from SISs must be demonstrated over the long term, and comparative trials to the current gold standard RPT and TOT slings are needed to solidify SISs as a first-line treatment option for women with SUI.

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CHAPTER 143

Mid-Urethral Slings for the Treatment of Female Stress Urinary Incontinence

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Introduction

Stress urinary incontinence (SUI) is a condition that affects the psychosocial welfare, interpersonal relationships, quality of life, productivity, and general health of afflicted women. Its prevalence has been reported to range from 14% to 46% in women older than 18 years of age [1–3]. The prevalence of SUI in women peaks at middle age and then declines slightly in favor of mixed and urge urinary incontinence thereafter [1, 2, 4, 5]. Despite this significant prevalence, due to the invasive nature and associated prolonged recovery of surgical options offered in the past, many women did not undergo treatment.

Since Ulmsten described the tension-free vaginal tape (TVT; Ethicon, Somerville, NJ, USA) procedure in 1995, "An ambulatory surgical procedure under local anesthesia for treatment of female urinary incontinence." mid-urethral synthetic slings (MUSS) have grown in acceptance and popularity to gain a leading position in SUI surgery [6]. They have become the new gold standard for the surgical treatment of female SUI, not only because of their simplicity for both the surgeon and the patient, but also because of excellent surgical outcomes and low morbidity. There are numerous studies, both randomized controlled trials (RCTs) and well-designed prospective studies, which provide a large amount of level 1 and 2 evidence that supports the concept of a sling placed at the level of the mid urethra. In addition, there is increasing evidence regarding how different approaches for placing a MUSS (retropubic and transobturator) can be applied to specific patient groups. This evidence base will be reviewed to help resolve clinical dilemmas concerning which type of sling to use in specific situations.

In this chapter we will also describe the anatomic basis and techniques of MUSS, examine their indications and outcomes, describe some of the newer "less invasive" techniques, and discuss the management of complications that can occur after MUSS placement.

Mechanism of action

The theoretical basis for the original TVT procedure was the "integral theory of female urinary continence," based on a series of anatomic studies of the female urethral closure mechanism performed by Petros and Ulmsten in the 1990s [7]. An important alternate theory, the "hammock" theory, was advanced by DeLancey in 1994 [8]. Both of these theories strive to explain how urethral pressure can be maintained above vesical pressure during increased intra-abdominal pressure. In the integral theory this is explained by opposing forces; the pelvic floor muscles act through their vaginal attachments to stretch the vaginal hammock against the pubourethral ligaments, shutting the urethra off from behind. Weakness in the pubourethral ligaments would lead to similar forces opening the urethra. The more practical "hammock theory" proposes that both urethral support and constriction are important. In this model, the support is provided by the layers outside the urethra on which it rests: the anterior vaginal wall, the endopelvic fascia between the arcus tendineus facia pelvic on each side, and the pelvic floor muscles. With increased

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intra-abdominal pressure, the urethra remains shut against this backboard, as long as it is intact. When the backboard is not intact, urethral hypermobility and/or SUI may result. It has been shown by ultrasound studies that placement of a sling at the mid urethra causes a dynamic kinking of the urethra with stress and thus can cure stress incontinence without affecting position or urethral mobility [9].

Anatomic approaches

Retropubic MUSS (Figure 143.1)

The original TVT procedure placed a polypropylene sling at the level of the mid urethra via a "bottom–top" approach. This involved the passage of a trocar from a mid-urethral vaginal incision through the endopelvic fascia and the retropubic space to a suprapubic exit point. The "top–bottom" technique was developed by Deval *et al.* [10] with the introduction of the suprapubic arc system (SPARC; American Medical Systems Inc, Minnetonka, MN, USA) sling. This technique involves passage of the trocar from a suprapubic incision (lateral to the midline) to a subepithelial vaginal dissection. Subsequently, there have been a number of different modifications of the "bottom–top" and "top–bottom" approaches using minor modifications of sling material and surgical instrumentation.

Transobturator MUSS (Figure 143.2)

The transobturator approach was introduced by Delorme *et al.* to avoid trocar passage in the retropubic space/pelvis, which addressed concerns over bladder, bowel, and major vessel injury and voiding dysfunction following TVT [11]. In this approach, vaginal dissection is as per the retropubic approach. Both transobturator approaches involve trocar passage between the vaginal incision, through the obturator membrane and obturator internus muscle to a groin incision below the adductor muscle insertion. The original transobturator tape (TOT) operation was described as an "outside–in" technique, with the tape being passed from the thigh into the vaginal incision (Uratape; Porges-Mentor, Le Plessis, Robinson, France). In 2003, de Leval further modified the technique: in this "inside–out," approach, a vaginal incision is made through the obturator foramen and out of the inner thigh [TVT-Obturator (TVT-O); Ethicon, Somerville, NJ, USA] [12].

Types of mesh

A number of different synthetic materials have been used as slings over the past decades. Both monofilament and multifilament materials have been tried. The ideal sling material should be inert, nonallergic, and relatively resistant to inflammation and infection. Synthetic meshes are divided into four groups: Type 1, macroporous, monofilament; Type 2, microporous; Type 3, macroporous, multifilament; and Type 4, submicronic, coated biomaterials with pore sizes of less than 1 µm. Since the introduction of the MUSS, it has become clear that slings made from Type 1 mesh are superior to other slings, predominately because they are relatively resistant to infection and inflammation.

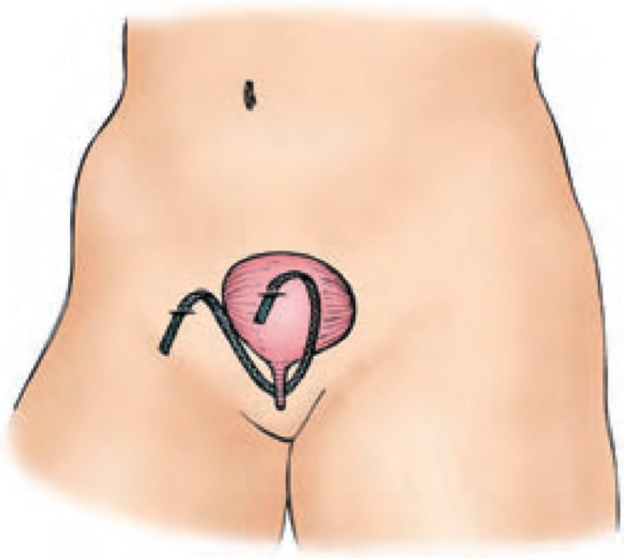

Figure 143.1 Tension-free vaginal tape (TVT) *in situ* (reproduced from Bullock, T.L., Ghoniem, G., Klutke, C.G., Staskin, D.R. Advances in female stress urinary incontinence: mid-urethral slings *BJU Int* 2006;98 (Suppl 1):32–40; discussion 41–42, with permission).

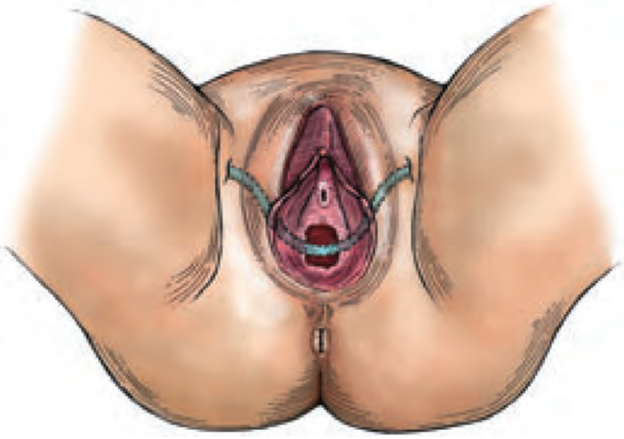

Figure 143.2 Transobturator tape (TOT) *in situ* (reproduced from Bullock, T.L., Ghoniem, G., Klutke, C.G., Staskin, D.R. Advances in female stress urinary incontinence: mid-urethral slings *BJU Int* 2006;98 (Suppl 1):32–40; discussion 41–42, with permission).

Table 143.1 Steps of the tension-free vaginal tape (TVT) procedure (modified from Ulmsten [16]).

1. Bladder is emptied at the outset of surgery. This allows passage of trocars around an empty bladder, reducing the chance of bladder perforation
2. Local anesthetic can be injected in the path of trocar placement and just below the vaginal epithelium to facilitate dissection in the correct anatomic plane beneath the epithelium but above the periurethral fascia
3. A 1.5-cm midline longitudinal vaginal incision is made, beginning approximately 0.5 cm proximal to the external urethral meatus, but not extending to the bladder neck to avoid bladder neck obstruction with the sling
4. Subepithelial plane is dissected laterally from the midline vaginal incision to the endopelvic fascia, minimizing disruption of structures through which the sling will pass. A space large enough to insert an index finger to palpate the endopelvic fascia is made
5. A stainless steel catheter guide is placed within the Foley catheter, allowing identification of the urethra and bladder neck during trocar passage. This may also help to position the bladder neck for trocar passage
6. Trocar (with attached TVT) is placed within the previously dissected subepithelial plane. The endopelvic fascia is perforated and the trocar is guided into and through the retropubic space. Close contact with the back of the pubic bone (and avoidance of lateral deviation) is necessary to avoid vascular or visceral injury
7. A small suprapubic incision is made bilaterally just above the pubic bone, about 2 cm lateral to the symphysis pubis, and the trocars exit here
8. Cystoscopy is preformed with a full bladder to make certain that there is no bladder or urethral injury. If there is an injury, the trocar is removed and repositioned
9. Trocar and attached tape are pulled up and the TVT is placed at the level of the mid urethra without tension a Hagar dilator, clamp or pair of scissors beneath the sling can be used to prevent overtightening)
10. In the awake patient, a cough test may be preformed to help adjust tension
11. Casing of the tape is removed
12. Vaginal wall is closed
13. Excess tape is excised at the level of the skin incisions on both sides and these are closed
14. (In most cases a catheter is not necessary postoperatively)

Slack *et al.* showed in an *in vivo* study that Type 1 mesh had an early and sustained filling with fibrous connective tissue and capillaries, showing that macroporous meshes promote tissue host ingrowth with resultant integration, allowing anchoring of the mesh within the tissue [13]. The provoked inflammatory response decreases markedly with time, thus reducing the risk of infection. Both type 2 and 3 meshes had a much more marked inflammatory response without as much fibrous ingrowth. ObTape in particular had barely any fibrous tissue or capillary ingrowth. These findings are in concordance with several other studies that support Type 1 mesh as having optimal qualities for use in suburethral slings. [13] The largest trial comparing monofilament and multifilament slings was published by Meschia *et al*. of 190 patients randomized to TVT or intravaginal slingplasty (IVS) [14]. At 24-month follow-up only vaginal erosion was significantly more common after IVS than TVT. In 2005, Domingo *et al.* reported a 13.8% extrusion rate for the ObTape [15]. Based on the above animal and clinical studies, all commercially available mid-urethral slings are now made from Type I, non-coated mesh (see Table 142.1).

Surgical technique

Retropubic MUSS

The original TVT technique and the SPARC techniques are described, recognizing that other slings are a variation on these techniques. Ulmsten's original technique described the use of intravenous sedation to allow for an intraoperative cough test and adjustment of sling tension [6]. This is not always employed now, so that general or regional anesthesia or sedation may be used.

The crucial steps of the TVT procedure are listed in Table 143.1 [16].

The SPARC technique is very similar except that the trocars are placed from the suprapubic incision downwards [10]. The vaginal incision is performed as for the TVT. After bilateral paraurethral dissection of the vaginal wall, two small horizontal suprapubic incisions were made, no more than 2 cm lateral to the midline, for needle entry. The needle is grasped with one hand on the handle and the other hand on the curved portion of the needle, near the abdominal incision, to control the direction of the needle tip. Then, the needle is passed through one of the suprapubic incisions, down the posterior side of the pubic bone towards the vaginal incision. The needle tip should remain in contact with the posterior pubic bone until it has passed through the endopelvic fascia. Using the index finger of the other hand, the surgeon locates the tip of the needle, then guides it through the vaginal incision. With the first needle in place, the surgeon inserts the second needle on the contralateral side, in the same way [10]. Cystoscopy is preformed to check for a bladder or urethral injury. The sling is attached to the end of each trocar and pulled up through the suprapubic incision. The sling is tensioned similarly to the TVT.

Transobturator MUSS

As with retropubic MUSS, a number of similar devices have been introduced, both outside–in [11] and inside-out [12]. Currently available commercial slings and their approaches are listed in Table 142.1. Anatomic studies have shown that with this method the synthetic sling is entirely outside the pelvis (and also retropubic space), within the foremost extension of the ischiorectal fossa [17, 18]. For "outside–in placement," the vaginal dissection is performed as per the original TVT operation. A puncture incision is made 15 mm lateral to the ischiopubic ramus on a horizontal line level with the clitoris. The trocar is held in the same hand as the side on which the operator is working. It is held vertically with the handle downwards; it is then introduced through the skin incision and crosses the obturator membrane. As the membrane is crossed, a specific resistance is felt and the handle is rotated to allow palpation of the tip on the finger within the vaginal fornix [19].

The "inside–out" technique differs in that a small introducer is placed beneath the vaginal epithelium and perforates the obturator membrane. The trocar is then introduced into its grooved surface and rotated 90° toward the thigh, exiting a skin incision made at the level of the clitoris and below the adductor longus tendon.

For both techniques it is important that the trocar (and tape) exit/enter the obturator foramen at its superior–medial border, away from the obturator vessels. TOTs tend to tighten when the casing is removed, therefore extra care needs to be taken to avoid this. Although the risk of bladder and urethral perforation are lower for transobturator versus retropubic sling placement, it is not zero. Therefore, we recommend performing cystoscopy after all transobturator sling placements to insure that the bladder and urethra have not been injured.

Results

Comparisons of outcomes in incontinence surgery are hampered by variations in definition of success. Definitions of cure may be subjective where the patient reports absence of stress incontinence, preferably by a validated questionnaire or instrument, or objective where the absence of incontinence is proven by a negative cough or pad test. In addition, various levels of subjective and objective improvement may constitute success depending upon the study protocols.

Long- and intermediate-term data are now available from a number of MUSS trials that provide level 2 evidence for durability of treatment. Nilson *et al*. have published long-term data for the original TVT procedure [20]. Their most recent publication provides level 2 evidence with a mean follow-up of 11.5 years for 69 of the 91 (77%) patients in their original series. Objective cure, defined in this group as negative cough test on examination or a 24-h pad test of less than 8 g, was found in 90% of women. Subjectively, 77% considered themselves cured based on the Patient Global Impression of Improvement (PGI-I). Intermediate term data are now available for the transobturator technique. Liapis *et al.* recently reported follow-up at 4 years for TVT-O with a cure rate of 82.4% in 74 patients, and Waltergny *et al.* reported 3-year follow-up of the original TOT series described by de Leval [12] with a cure rate of 88.4% [21, 22].

Perhaps the best way to describe the results of MUSS is to look at the level 1 and 2 evidence of various randomized controlled and comparator trials. These trials compare MUSS to other surgical procedures. Most of these studies contain "index" patients who are patients with SUI only and evidence of urethral hypermobility. We will also discuss the use of slings in patients other than these patients and present the evidence regarding their success in these groups.

There have been several high-quality reviews of the literature on synthetic slings. A recent Cochrane review by Ogah *et al*. found 62 randomized trials including synthetic slings [23]. These included comparisons between synthetic slings and traditional sling operations or colposuspension, retropubic "top-down" versus "bottom-up" approaches, transobturator "outside–in" versus "inside–out", and retropubic versus transobturator route. Prior to this Novara *et al*. had reviewed the complication rates in a meta-analysis published in 2008 [24].

MUSS versus other surgical procedures for stress urinary incontinence

Initial level 1 evidence for TVT comes from the Ward and Hilton trial, a multicenter randomized controlled trial of TVT versus Burch colposuspension [25]. In the original publication, the authors showed that TVT and colposuspension have equivalent efficacy (based on very strict criteria, with "lost to follow-up" considered a failure), with 51% cure for TVT versus 63% for Burch colposuspension. The authors also reported 5-year follow-up data on 117 patients [26]. For the primary efficacy variable of a negative 1-h stress pad test, there was no difference in success (81% vs 90%). Furthermore, secondary variables of cure of stress leakage (63% vs 70%), and satisfied or very satisfied (91% vs 90%) showed no difference. Hospital stay was significantly shorter for the sling group. There was no difference in the chance of reoperation. However, patients who had colposuspension were more likely to require prolapse surgery (7.5% vs 1.8%). The authors did note that identifying true durability of cure was somewhat hampered by loss to follow-up across both groups, as only 119 of the original 377 patients had full 5-year subjective and objective datasets. A sub-analysis of the trial by Manca *et al.* showed that TVT was more cost-effective than Burch colposuspension, with greater gains in quality-of-life years gained [27].

The Cochrane review found nine randomized trials comparing MUSS to traditional slings. MUSS had a shorter operative time (35 vs 87 min) and shorter hospital stays [relative risk (RR) = 0.5]. Different quality-of-life (QoL) measures were used in each study, but all showed similar outcomes for traditional versus synthetic slings [23].

For open colposuspension versus slings, nine randomized trials were included. Objective cure rates at 12 months (n = 729) were 79% for synthetic slings versus 82% for colposuspension. For laparoscopic colposuspension versus slings, the combined results of six trials showed no significant difference in patient-reported outcomes within 12 months; 80% for slings versus 74% for colposuspension. By clinician assessment there was a significant difference in favor of synthetic slings (89% vs 78%) [23].

Comparator trials for retropubic MUSS

The Cochrane review found three trials reporting on patient-reported cure (defined as absence of leakage on stress) for retropubic MUSS; these showed a significant difference in favor of the "bottom–top" versus "top–bottom" approach at 12 months (85% vs 77%) [23]. The combined analysis of objective cure rate (by pad test or stress test) also favored the bottom–top, but by a smaller margin (92% vs 87%).

Comparator trials for transobturator MUSS

There are four randomized studies which directly compare "outside–in" to "inside–out" transobturator slings [28–31] These demonstrate equivalent cure rates over the short and medium term; objective cure rates range from 83% to 98% for outside–in, and from 87% to 90% for inside–out. By subjective measures, most often the PGI-I, cure rates for inside–out ranged from 83% to 90.7%, and for outside–in from 77% to 88.7%. Similarly in Latthe *et al.*'s meta-analysis of transobturator slings, indirect comparison of TVT-O and TOT showed equivalent cure rates [32].

Rretropubic versus transobturator approaches

Two meta-analyses have compared retropubic with transobturator slings. In 2003, Sung *et al.* identified 18 eligible studies, both randomized (492 patients) and cohort (2099 patients) [33]. They were unable to assess a pooled estimate for objective cure as only one randomized study reported this and the four cohort studies used different definitions for reporting. The cohort studies showed a 12.3% failure rate for the transobturator and a 13.7% failure rate for the retropubic approach. The pooled odds ratio (OR) for subjective failure in five of six randomized studies reporting this, was 0.85 (95% CI 0.38–1.92), and the failure rate in the transobturator group was 5.7% versus 7.8% in the retropubic group. These results did not change when patients only with greater than 1-year follow-up were analyzed. Results from the pooled subjective outcomes from cohort studies were similar with an OR of 0.73. This led these authors to conclude that there was no statistically significant difference in subjective outcomes between the two approaches. They do caution, however, that this does not mean that there is no difference, simply that the data available to them did not show a difference.

Long *et al*. have compared the approaches in a meta-analysis of the more recent literature, January 2008 to March 2009 [34]. They identified 11 studies, six RCTs and five cohort studies. Again, reported outcomes differed between studies; three RCTs reported on objective cure, one on subjective cure, and two on changes in QoL or reoperation rate. The short-term cure rate was borderline inferior for the TOT group (OR 0.62, 95% CI 0.37–1.00), nearly reaching statistical significance ($P = .05$). The authors commented that this result could be due to inclusion of Schierlitz *et al*.'s study of women with intrinsic sphincter deficiency (ISD) (see below) [35].

In the recent Cochrane review, Ogah *et al*. reviewed 24 trials that compared the retropubic and transobturator approaches of MUSS placement [23]. Subjective cure was reported in 10 trials with a total of 1281 participants, and showed no statistically significant difference between routes. In 17 trials with 2434 participants, women were slightly less likely to be objectively cured with the transobturator route (84%) compared with the retropubic route (88%); the RR for objective cure was 0.96 at 12 months (95% CI 0.93–0.99), although there was no significant difference in subjective cure rates (83% in both groups; RR 1.01, 95% CI 0.96–1.05).

Sung *et al*. in their review of six RCTs and 11 cohort studies in 2591 women showed no difference in subjective failure rate between the two routes; 5.7% for transobturator versus 7.8% for retropubic in the RCTs, and 15.4% for transobturator versus 12.8% for retropubic in the cohort studies. They did, however, note a lower risk of complications and *de novo* irritative voiding symptoms for the transobturator group. They concluded that it would take an RCT of 30 000 women to demonstrate superiority of one approach over the other. Similarly, Latthe *et al.* found a total of 14 trials comparing either TVT-O or TOT to TVT, and showed no difference in subjective cure rate [36].

Based on these studies we believe that for the index patient, transobturator and retropubic MUSS offer similar efficacy, with perhaps a slight advantage for the transobturator approach with respect to intraoperative and long-term complications.

Results for MUSS in special populations

Mixed incontinence

With any SUI operation in the patient with mixed symptoms, there are always concerns about lower cure rates for the stress component, and persistent urgency and urgency incontinence for the overactive bladder component. With respect to cure of the stress SUI, studies on MUSS have shown favorable results. Duckett *et al*. studied 51 of 344 women undergoing TVT who had both detrusor overactivity (DO) and urodynamic SUI [37]. They found that SUI was cured in 92%, with an objective cure of DO in 47%, and resolution of urgency incontinence in about 60%. Similarly, Nilsson's update of the original series in 2001 included 59 (of 161) patients with mixed urinary incontinence (MUI), but no DO [38]. At a mean follow-up of 16.7 months, the cure rate for MUI patients of 81.4% was not statistically different from that for patients with pure stress incontinence (88%).

Two studies by Paick *et al*. reported on patients with MUI [39, 40]. The first, which reported on 73 of 274 patients with MUI who underwent TVT with at least 6-month follow-up, showed that the MUI group had the same cure rate for SUI as the SUI-only group. They also found that 16.4% of the MUI group had persistent urgency incontinence, so that overall urinary continence cure was lower for the MUI than the SUI group, but still quite favorable (78.1% vs 95.5%) [39]. In their second study, they reported on 144 women with MUI. Cure rates for SUI only showed no statistical difference for TVT, SPARC, and TOT at 95.8%, 909.9%, and 94%, respectively [40]. Results were also not statistically different for total cure (incorporating urge incontinence) with TVT, SPARC, and TOT showing rates of 81.9%, 77.3%, and 78%, respectively. There were no risk factors for cure of SUI but DO on urodynamic study was a risk factor for treatment failure of urinary urge incontinence. There was one notable difference between preoperative characteristics between the groups: the TOT patients had significantly less severe incontinence than both the SPARC and TVT patients.

To further stratify patients with MUI, a study of 1113 patients compared those who presented with predominant stress, equal stress and urgency, and predominant urgency incontinence [41]. Preoperative urodynamic parameters, including DO, were not reported in this study. Overall outcomes in these MUI populations were good; 87.3% and 82.7% were stress test dry at 7 and 38 months of follow-up, respectively. These authors had strict standards for cure; for subjective cure this was both being very satisfied and having stress and urgency indices of 2 or less on standardized questionnaires, while objective cure had to include a negative stress test (pad test <10 g). There was no difference in rates of "stress test dry" at 7 and 38 months between the groups, though there was a trend to lower cure rates for urgency-predominant incontinence at 38 months (75.3% compared to 84.7% for stress-predominant incontinence). There were, however, statistically significant differences between objective and subjective cure, pad test dry, and patient satisfaction for predominant stress versus predominant urgency patients at 7 and 38 months, with urgency-predominant incontinent patients faring worst in all parameters. Also, these authors found that rates of urgency incontinence compared with preoperative status deteriorated between 7 and 38 months. Holmgren *et al.* also showed deterioration over time in 2–8-year follow-up [41]. Women with pure stress incontinence maintained a cure rate of 82% to 8 years, whereas women with MUI had a lower cure rate: 60% to 4 years with a further decline to 30% in patients at 4–8 years after surgery.

Overall these results suggest that women with MUI can do well with sling surgery with respect to SUI; however, they should be carefully counseled that urge symptoms can persist with significant impact on patient satisfaction. We believe that women should not be excluded for MUSS surgery based on the presence of urgency incontinence or symptoms.

Obesity

There are no prospective randomized studies that have examined obesity as an independent variable across different surgical procedures to treat SUI. Six published studies that have shown that there is no decrease in cure after TVT, and one study has shown a difference [42, 43]. Most recently, a retrospective study by Killingsworth *et al*. reviewed outcomes in TVT at 1 year by PGI-I, urogenital distress inventory (UDI-6), and incontinence impact questionnaire (IIQ-7), finding no differences in satisfaction, improvement in QoL, and complications between three groups of normal [<body mass index (BMI) 25], overweight (25–30), and obese (>30) women [42]. A single study by Hellberg *et al*., where 970 women were telephone surveyed post TVT (mean follow-up 5.6 years), showed significant differences in cure from 81.2% in those with a BMI less than 25 to 52.1% cure in those with a BMI greater than 35 [43]. However, this study did not control for preoperative symptom severity and did not use a standardized questionnaire. There are no data specifically reporting outcomes for transobturator slings in obese women.

Elderly

The affect of age on outcomes of MUSS is relatively undefined. There are a number of confounding variables, such as a higher rate of DO and ISD in the elderly. Also, the definition of elderly varies between studies. At best we can say that there is conflicting evidence regarding age and its impact on MUSS outcomes. Liapis *et al.* reported a cure rate of 76.4% in 55 patients with a mean age of 75.4 years [44]. Pugsley *et al.* reported a cure rate of 77% for women over 70 years compared to 92% for those younger than 70 years undergoing TVT and colposuspension; however, there was considerable disparity in number with only 22 in the older group versus 100 in the younger Group [45]. Sevestre *et al.* demonstrated a cure rate of 67% in 76 patients with a mean age of 76 [46]. Hellberg *et al.* also analyzed their results for TVT in the "very old" versus other patients, finding a reduced cure rate of 56% for those older than 75 years compared to 80% for those younger than 75 years [43]. Conversely, Gordon *et al.* demonstrated similar cure rates between younger (mean age 57.8 years, n = 208) and older (mean age 74.9 years, n = 123) patients undergoing TVT at 12 months, with absence of persistent stress incontinence in 6% and 7%, respectively. A significant difference between these groups was the frequency of concomitant prolapse repair (81% of older women vs 67% of younger women) [47]. Two other studies have also reported equivalence between these groups for TVT [48, 49]. Campeau *et al.* compared immediate to 6-month delayed placement of TVT in 69 women aged over 70 years. At 6 months, the sling group had improved QoL and patient satisfaction compared to the delayed group [50].

Perioperative morbidity and complications are also a consideration in older patients, with several authors showing higher rates in elderly patients. Gordon *et al.*'s study showed the risk of *de novo* urge was 18% at 1 year in older patients versus 4% in younger patients [47]. Also, in the elderly group there were two cases of pulmonary embolism, two of cardiac arrhythmia, one of severe pneumonia, and one of deep vein thrombosis, compared with none of these in the younger group other than one cardiac arrhythmia. Pugsley *et al.* showed that there was higher rates of patients requiring intermittent self-catheterization, UTI, and division of tape (OR = 29). Campeau *et al.* reported significant perioperative complications: bladder perforation (22.6%), urinary retention (12.9%), UTI (3.2%), and *de novo* urgency (3.2%) [50]. At present there are no studies that report on transobturator slings specifically in an elderly population.

Recurrent stress urinary incontinence

There are several studies that specifically address surgery for recurrent stress incontinence after failed transobturator or retropubic slings or mini-slings. Liapis *et al.* recently published a series of 31 such patients [51]. They found the overall cure rate when placing a TVT in patients with recurrent SUI was 74%. However, it was highest (>80%) in those who had urethral hypermobility and no ISD. Success was reduced but satisfactory (63%) with low urethral mobility (<30°) and no ISD, and was low (40%) with both ISD and a fixed urethra. Meschia *et al.* included 25 of 301 patients with previous anti-incontinence procedures in their series using TVT, and demonstrated a lower cure rate of 72% for recurrent versus 89% for primary treatment [52]. Biggs *et al.* showed successful use of a transobturator sling in women with failed prior surgery for SUI. In a series of 27 women with urethral hypermobility who underwent TVT-O they reported an 80% success rate assessed by PGI-I (very much better or much better) at mean follow-up of 25.7 months [53]. Stav *et al.* recently showed that repeat placement of a mid-urethral sling resulted in a lower subjective cure rate than primary placement (62% vs 86%) [54]. They also showed that a repeat retropubic sling was more successful than a repeat transobturator sling (71% vs 48%). Both these results may in part be due to the higher rate of ISD in repeat candidates (31% vs 13%). Also of note, the rates of *de novo* urgency (30% vs 14%) and *de novo* urgency incontinence (22% vs 5%) were higher in the repeat group.

Concomitant prolapse surgery/hysterectomy

Groutz *et al.* published their series of 100 clinically continent women with occult SUI with prolapse reduction [55]. At mean follow-up of 27 months, results were comparable with "index" patients. Only two patients had symptomatic SUI at 1 year. In addition, perioperative morbidity was low, with only two patients requiring catheterization of more than 7 days and *de novo* urgency in 8%, which is comparable with sling-only series. Liang *et al.* reported a series of patients undergoing hysterectomy and prolapse repair with pessary reduction of the prolapse during preoperative urodynamic testing [56]. Patients with a positive pessary test (occult SUI) were randomized to TVT or no TVT. The rate of postoperative subjective SUI was significantly lower in those who had a TVT placed (10% vs 65%). No patients with a negative pessary test (none had a sling) had postoperative SUI. A previous prospective trial with 3-year follow up by Meltoma *et al.*, found that concomitant vaginal surgery did not affect outcome of TVT; however, there was an increased rate of complications such as infection, bladder perforation, and transient retention after TVT [57]. Ballert *et al.* used urodynamics to decide which patients should have a MUSS placed with prolapse repair [58]. Patients who had urodynamic-proved SUI and occult SUI (with the prolapse reduced, SUI demonstrated during urodynamic study) had a MUSS placed. There is an ongoing trial addressing prophylactic sling placement, the OPUS trial [59].

Based on the currently available literature, it would appear that MUSS is a good choice for the treatment of concomitant SUI and prolapse, and may also be effective in reducing the risk of postoperative SUI in women with occult SUI.

Intrinsic sphincter deficiency

ISD represents the portion of SUI that is not due to a support defect or urethral mobility. ISD is difficult to quantify and even more difficult to diagnose in patients who also have urethral mobility. Most of the literature has used a definition of an abdominal leak point pressure (ALPP) of less than 60 cmH_2O or a maximum urethral closure pressure (MUCP) of less than 20 cmH_2O. While we would agree that these lower resistance urethras are probably more difficult to treat, it cannot be said with certainty that the lower resistance is due to ISD rather than a support defect (except in the fixed urethra). Nevertheless the literature has made that distinction and for the purpose of this review we will accept these criteria. More recently, ISD and urethral hypermobility have been viewed as a spectrum of disease with overlap. Thus, recent research examines the contributions of ISD *and* urethral hypermobility to outcomes.

Retropubic MUSS has been shown to be effective in treating this group of patients. Rezapour *et al*. reported on their long-term results in patients with ISD, defined as MUCP less than 20 cmH_2O, at 2 years, with cure rates of 74%, improved 12.5%, and no change 12% [60]. These results compare favorably with their and other authors' results for all comers with SUI. There are five studies (one cohort, one retrospective review, and three randomized trials) that favor retropubic over transobturator MUSS, and one RCT showing equivalence in patients with ISD [61] (variably defined as MUCP < 20 cmH_2O or ALPP < 60 cmH_2O). Fritel *et al*. showed that TVT was most effective in treating the hypermobile urethra, but had acceptable success rates for the relatively fixed urethra also [62]. Success rates at 9 months were 97% with the Q-tip test at greater than 60°, 86% at 30–60°, and 70% at less than 30°. There was no difference in success based on MUCP greater or less than 20 cmH_2O. A recent small study ($n = 65$) by Haliloglu *et al.* of urethral hypermobility (Q-tip test $\geq 30°$) and ISD (ALPP < 60 cmH_2O) with TOT found that cure rates at 24 months (defined as a negative cough test) were: urethral hypermobility, no ISD 96.4% ($n = 31$); urethral hypermobility and ISD 87.5% ($n = 18$); and no urethral hypermobility and ISD 66.7% ($n = 16$) [63]. They concluded that a lack of urethral hypermobility may be a risk factor for TOT failure and suggested that even in the presence of low leak point pressures suggestive of ISD, the coexistence of urethral hypermobility still indicates likely good outcomes with transobturator MUSS.

Based on the available data it would appear that MUSS, retropubic or transobturator, works well in cases of low urethral resistance with hypermobility. The literature suggests that ISD patients may do better with retropubic MUSS, but the evidence for this is not strong enough to support a high-level recommendation. In cases of a more fixed urethra, there are more data to support the retropubic approach over the transobturator approach, but again the level of recommendation would be relatively low.

Single-incision slings

Although retropubic and transobturator MUSS are considered minimally invasive procedures, there have been more recent developments to make the procedures even less invasive. The single incision or "mini-slings" slings are designed to be placed via a small vaginal incision (like the traditional MUSS) but without any exit incisions. Theses sling can be place like a "hammock" (mimicking the transobturator slings) or like a "U" (mimicking retropubic slings) (see Chapter 142). There are a number of single-incision slings available, and new ones are constantly being introduced. The original single-incision slings and the ones for which some data are available are the TVT-Secur (Ethicon Women's Health & Urology, Somerville, NJ, USA), and the MiniArc (American Medical Systems Inc, Minnetonka, MN, USA),. The TVT-Secur can be placed into the endopelvic fascia in a U form or into the obturator internus muscle in a hammock form, while the MiniArc is placed only as a hammock.

To date there is a paucity of peer-reviewed publications and level 1 evidence in this emerging area. Available data are short term only with mixed results, with some studies demonstrating equivalent cure rates to traditional transobturator and retropubic approaches and others showing less favorable results (Table 143.2). There are no peer-reviewed published level 1 comparative trails of single-incision slings versus traditional MUSS, to establish their place in evidence-based practice. In theory, these procedures could offer a quicker recovery, but that is yet to be demonstrated. Notably, there have been case reports of complications despite the extremely minimally invasive nature of the procedure. Masata *et al.* described severe bleeding from the internal obturator muscle following TVT-Secur, with 1 L of blood loss requiring repeat surgical exploration [64].

We believe that single-incision slings hold promise for the treatment of female SUI as they rely on the same principles as other MUSS. At the time of this writing,

Table 143.2 Results of available studies of mini-slings (number of subjects, results, and complications have been pooled from all the listed studies).

Mini-sling	Main study	Number of subjects	Technique	Results	Complications
Contasure Needleless	Navazo *et al.* (2009) [83]	120	Forceps penetrates Ob foramen, grasps pocket. No needles	Cure 84% Failure 8%	Vaginal erosion 2.5% Urinary retention 1.7%
MiniArc	Gauruder-Burmester and Popkin (2009) [84], Moore *et al.* (2009) [85] Debodinance and Delporte (2009) [86, 87]	230	Self-fixating tips in obturator membrane	1-year cure rates: 69.1%, 77%, 94%	*De novo* urge, 36.8% Bladder perforation 1% Hematoma 1% One erosion, one *de novo* urge Urinary retention 1.6%
TVT-Secur	Neuman *et al.* (2008) [88] Martan *et al.* (2009) [89] Oliveira *et al.* (2009) [90] Meschia *et al.* (2011) [91] Gorlero *et al.* (2009) [92]	423		62%, 71%, 81%, 88.6–92% at 1 year	Vaginal perforation 8% first 50 + 12% (other) vaginal trimming 0.6% *de novo* urge One vaginal erosion

evaluation of these techniques is hampered by short follow-up, limited data, and mixed outcomes, and so these slings have yet to establish their place in the armamentarium of sling surgery.

Complications and their managementWe will outline the incidence of complications and briefly discuss management for intraoperative complications (bladder, urethral, viscous and vessels injury), immediate postoperative complications (voiding dysfunction, groin pain, infection), and chronic problems (*de novo* urgency, sling erosion/extrusion).

Bladder perforation

Bladder perforation occurs in approximately 3.4% of patients during TVT [24]. Transobturator slings were conceived to reduce the risk of bladder (and vessel) injury by avoiding the retropubic space. Three recent reviews have confirmed this. The recent Cochrane review identified 18 trials reporting on bladder perforation and pooled data to show that TOT had significantly lower rates of bladder injury than retropubic slings (0.3% vs 5.5%). Novara *et al*., in an analysis of nonrandomized data, reported that TOT was statistically less likely to cause perforation than retropubic slings [24], and Latthe *et al*., in their meta-analysis of trials comparing TVT-O and TOT versus TVT, reported ORs of bladder injury of 0.11 and 0.15, respectively [32].

Bladder perforations recognized intraoperatively can be managed by removal and replacement of the tape. Cystoscopic confirmation that the final position is indeed outside the bladder is crucial.

Urethral injury is a rare occurrence with both retropubic and transobturator MUSS. Like bladder injuries, they are treated by removing the tape. In cases of a large injury, consideration should be given to aborting the procedure and allowing urethral healing for 3 months before inserting a new sling.

Vascular and bowel injuries

An important paper was published by Deng *et al.* in 2007 regarding the reporting of major complications after MUSS surgery [65]. They reviewed the literature and compared this to reporting through the Food and Drug Administration (FDA) manufacturer and user facility device experience (MAUDE) database (queried for self-reported complications) for the same time period. Their review of the world literature for 2001–2005 found the rate of major complications to be 0.8%, with no reported deaths. There were a total of 928 complications reported to the MAUDE database in that time period, of which 161 were major, with 10 resulting in death. Notable differences were noted, with 36 serious vascular injuries and 38 bowel injuries in the MAUDE database, but only two vascular and three bowel injuries reported in the literature for 2001–2005.

Vascular injury occurs very rarely; however, it is a devastating complication for a QoL procedure. National registries provide the best indicators of worldwide incidence, and these were reviewed by Sivanesan *et al*. [66, 67]. The reported incidences of vascular injury were: 0% (of 1455) in the Finnish registry, 0.8% (of 5578) (reintervention or conversion rate) in the Austrian registry, 0.03% (of 2280) in the French registry, and 0.1% (of 809) in the Dutch registry [68].

Management depends on the patient's hemodynamic status; in those who are stable, angiographic embolization avoids further operative morbidity, while those who are unstable may require laparotomy and control of bleeding.

Bowel injury is also a very rare complication in the literature, estimated at less than 1%. Two cases occurred among 12 280 cases in the French registry for TVT [68]. Ten cases were reported after TVT in the FDA MAUDE database. In Daneghasri *et al.*'s review of complications in 2008, six deaths had resulted from bowel injury [69]. No cases of bowel injury have been reported after TOT.

Voiding dysfunction and obstruction

Varying rates of voiding dysfunction have been reported after sling surgery. The Cochrane review found that transobturator slings had a lower incidence than retropubic slings (4% vs 7%) [23]. Patients may present early with retention, or late with obstructive voiding symptoms: feeling of incomplete emptying, straining or hesitancy, needing to lean forward or stand, partial or complete urinary retention, or symptoms suggesting overflow incontinence. Symptoms of *de novo* urge may be secondary to urethral obstruction and while not absolute indicators in themselves of voiding dysfunction, refractory symptoms with timing associated with intervention or association with voiding symptoms should alert the physician to the possibility of obstruction. It is especially important to document the relationship of symptom onset to surgery. If patients report symptoms of voiding dysfunction, a free flow rate should be measured. The necessity of urodynamics in this setting is controversial. We would not consider them to be always necessary in the setting of classic obstructive voiding symptoms, retention, or high postvoid residual (PVR) (with normal preoperative PVR) (unpublished data). However, video urodynamics are useful in patients with storage symptoms to determine whether obstruction is present at the level of the sling.

Conservative management includes observation for irritative/storage symptoms and clean intermittent self-catheterization for high PVR and retention. Small series have been published reporting techniques and outcomes for sling loosening/lysis. Klutke *et al*. described 17 patients (2.8% of a 600 patient series) who presented with obstructive symptoms following TVT [70]. The time to sling loosening or cutting ranged from 6 to 228 days. Two techniques were used in this study: the "Washington University" technique uses a right-angled clamp to identify the sling which is then transected, and the "Minneapolis" technique, in which sling is identified and loosened with Metzenbaum scissors with downward traction without sling transection. All 17 patients in this series had immediate postoperative relief of symptoms with ability to void. One patient had recurrence of stress incontinence.

Rardin *et al*. described 23 patients with persistent voiding dysfunction (1.9% of 1175) who underwent TVT [71]. The mean interval between TVT placement and release was 17.3 weeks. In this study, all tapes were transected or segmentally excised. Presenting symptoms were impaired bladder emptying in 20, three had severe irritative symptoms, and seven had both. Seven patients had urethral dilation after TVT placement without resolution of symptoms. Resolution of voiding symptoms differed by symptom. Impaired emptying resolved in all cases, but complete resolution of irritative symptoms occurred in only 30% of cases at 6 weeks, the study endpoint. Stress incontinence recurred partially in 26% and completely in 13% of patients.

Patients with storage/irritative symptoms should also be warned that in a study of 44 patients undergoing sling take down or urethrolysis, two-thirds of patients with preoperative storage/irritative symptoms still had them postoperatively. Only 14 patients with suburethral synthetic slings (all TVT) were included in this study, so the numbers may not be sufficient to draw conclusions from this study alone [72].

With respect to timing of sling loosening or cutting, we favor an approach of early tape loosening for severe obstructive symptoms and retention. Several small series now suggest that early intervention should be favored as delayed intervention may lead to irreversible bladder symptoms. Leng *et al*. published a series of 21 patients who underwent sling lysis. When they stratified patients by their postoperative symptoms or absence of these, there was a statistically significant difference in mean time to sling lysis (9 months in the no symptom vs 31 months in the persistent symptom group) [73]. South *et al*. showed a similar trend, although their series had relatively small number of cases of synthetic slings [74].

Nguyen published his series of 10 women who underwent tape loosening (under anesthesia) at 3–10 days. All the women were spontaneously voiding after this procedure and there were no recurrences of obstruction or SUI at 1-year follow-up [75]. Price *et al*. recently published their series of 33 women who had early sling loosening (mean 7.7 days) under general anesthesia [76]. This was successful in 29 women, with four requiring tape division at 4–8 months. All patients had resolution of voiding symptoms, with one of the four tape-division patients having the only recurrence of stress incontinence.

We consider intervention for patients who have retention or near retention at 1–2 weeks. For early intervention, sling loosening in the office or operating room can be considered. We perform this procedure in a similar fashion under local anesthesia in the office and have found this to be well tolerated. After injection of local anesthesia, the incision is opened by removing the prior closure suture. The sling is hooked with a clamp and the clamp is spread. If this fails to loosen the sling, it can be cut. Animal studies have shown fibroblast infiltration of the tape at 1 week, which supports Price *et al*.'s observation that tapes cannot be loosened after 2 weeks. At this point, it is easiest to cut the tape in the operating room setting.

For persistent voiding dysfunction after a MUSS has been formally cut, a formal transvaginal urethrolysis is the next step. It can be done through a midline vaginal incision. Fortunately, this is rarely required.

Groin pain

Groin pain may occur after transobturator slings, has been reported but is rare after retropubic slings. In Latthe *et al*.'s systematic review, this occurred in 12% of the transobturator group compared to 0.9% of the TVT group (OR = 8.28). Similarly the Cochrane review found a 12% incidence of groin pain in the TOT group versus 1.7% in the retropubic group (RR = 6) [36]. The differential diagnosis of persistent groin pain after TOT includes: adductor muscle strain, osteitis pubis, obturator/groin abscess, structural adhesions, and inflammation, edema or nerve entrapment of the anterior branch of the obturator nerve. There is a limited amount of literature regarding treatment of pain.

Work-up should include examination and laboratory tests to exclude hematoma and infection. MRI can visualize edema, hemorrhage, and the obturator nerve itself; however, it cannot see the polypropylene tape or smaller branches of the nerve. Described management includes pain medications, steroids, and excision of part or all of the sling Hazewinkels *et al.* advised against delaying sling removal, as further scar tissue deposition can hamper removal and nerve damage may become irreversible [77].

Infection

Seven cases of abscess (associated with vaginal erosion) following TOT placement were reported in the Austrian registry [78]. The authors concluded that these seemed to be more common after transobturator than retropubic tapes; however, four of the abscesses were associated with the ObTape, a 50-µm pore tape that has been removed from market [78]. Infections are rare with the current type 1 macroporous meshes. Treatment requires complete excision of the infected tape.

Lower urinary tract symptoms

De novo urgency can occur following sling surgery with rates ranging from 3% to 25.9%. Holmgren *et al*. reported on a series at a mean follow-up of 5.6 years and discussed several important findings [79]; patients with urgency will experience lower quality even if their stress incontinence is cured, urgency incontinence may not be reported in sling failure rates, and urgency symptoms may not be transient (in fact the proportion of the group with urgency remained consistent over time). They compared women with and without *de novo* urgency and showed there were large and significant differences in QoL scores; the women with *de novo* urgency had an IIQ-7 of 28.1, as compared to 5.6 for those in the comparison group ($P = .0001$). For the UDI-6, the corresponding rates were 49.6 and 13.6, respectively ($P = .0001$). They discussed that persistent incontinence, now of the urgency type, may not be reported as failure in many series where success is the absence of leakage on stress testing or patient reported stress incontinence, although they noted that urge and urgency incontinence may be more bothersome to women in everyday life than stress incontinence. In their series, 51 of 67 patients with *de novo* urgency in this series had actual episodes of incontinence. While most authors report that *de novo* urgency will be transient, these authors showed that 14.5% of women experienced this symptom with similar frequency across a duration of 2–8 years after TVT surgery.

Transobsturator slings have a lower rate of storage symptoms, with pooled results from eight RCTs comparing retropubic to transobtrurator approaches showing an OR of 1.81 [23].

Vaginal erosion/extrusion

The rate of vaginal erosion/extrusion is reported at 1%. The Cochrane review found that the vaginal extrusion rate was higher in the TOT than the TVT group (OR = 1.51; 95% CI 0.51–4.43) [23]. On subgroup analysis, the erosion was seen more often in the TOT group (OR = 2.37, 95% CI 0.53–10.63) and less often in the

TVT-O group (OR = 0.86; 95% CI 0.17–4.35) when compared with TVT.. Latthe *et al*. also found the transobturator path to have a higher risk of vaginal injury (OR = 3.58) [32].

Similar to bladder mesh erosion, some vaginal erosions may represent unreognized vaginal perforation (especially at the vaginal fornices) intraoperatively.

Symptoms of vaginal extrusion include malodorous vaginal discharge, postcoital spotting, dyspareunia (patient and partner), vaginal bleeding, and UTIs.

Management of extrusion optimally involves surgical removal of that portion of the tape. Some have described trying a course of conservative therapy with estrogen cream.

Sexual function

Several studies show equivalent results for sexual function after TOT and retropubic slings. They also demonstrate that while there are significant numbers of women who improve (29–32%), there are also some who deteriorate following anti-incontinence surgery 12.5–17.3%), with no difference demonstrated by Senthilhes *et al.* in their recent comparison between transobturator and retropubic synthetic slings [80].

Bladder and urethral erosion

Fortunately erosion of MUSS into the bladder or urethra is a rare occurrence. When it is recognized, the first question that must be asked is whether it is a true erosion or a missed injury. In 14 randomized trials reviewed by Novara *et al*, only three reported on this, with rates from 0% to 1.8% for transobtruator and 0% to –1.9% for retropubic slings. In 34 nonrandomized trials of TVT with at least 24-month follow-up, four reported on this with similar rates ranging from 0% to 1.8% [24]. Many authors believe that erosion into the bladder actually represents slings inadvertently placed through or in the wall of the bladder at the time of surgery. McLennan *et al.* demonstrated a learning curve with respect to bladder perforation [81]. Residents' cases were grouped into numbers of five; the rate of injury in the first five was 40.9%, 30.7% in second five, and 25.9% in the third five; the differences were statistically significant. Overall, there was a significant rate of missed perforation on cystoscopy with 35 of the 95 injuries missed by residents (37%). This emphasizes the need for thorough cystoscopic examination at the time of surgery, to avoid missed perforations which present as "bladder erosions" [81]. Such injuries may present with UTIs, bleeding or bladder stones. Treatment requires removal of the sling from the bladder. Endoscopic techniques with endoscopic scissors and laser, laparoscopic techniques via the bladder, and open excision are used.

A recent series of 14 urethral injuries following sling surgery was published by Morton and Hilton [82]. Their patients had undergone TVT, SPARC, TOT, and TVT-O types of slings. Their pathologies included six perforations/erosions, four diverticula, and four urethrovaginal fistulas. Most of the patients had had abnormal symptoms following sling insertion, including urinary retention, persistent incontinence or obstructed voiding. Each of these patients required reconstructive surgery, with seven of 14 having significant persistence of overactive bladder symptoms, one voiding difficulty, and one persistent groin pain. These authors also performed a literature search for further cases, finding four further reports of urethral diverticula and 15 urogenital fistulas. The authors used case series report of urethral perforation to calculate rates of urethral perforation: 0.88% for retropubic slings and 1.09% for transobturator slings. Whilst the authors acknowledge that it is difficult to determine the true denominator, they conclude that the incidence of urethral injury appears no lower for the transobturator than the retropubic route. Thus, they emphasize the importance of operative cystoscopy in all types of slings.

The mechanism by which urethral erosion occurs is probably dissection into the incorrect anatomic planes around the urethra where dissection is too close to the urethra within the periurethral fascia or if the sling is placed under tension, . Data from the Austrian registry reported urethra/bladder erosion in 0.5% [78].

Urethral erosion requires removal of the eroded portion of sling and primary closure or urethral reconstruction with vaginal/martius flaps.

Conclusions

MUSS have revolutionized female incontinence surgery. From their inception they offered comparable efficacy to existing operations with improved ease of performance for the surgeon and improved postoperative morbidity for the patient. These results have proven durable in the long term. Further innovation of the technique includes the emergence of transobturator and minislings. Whilst complications of these slings are relatively rare, surgeons who perform these operations should mindful of their symptoms so that management of these is expedient.

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CHAPTER 144

Maxi/Pubovaginal Sling

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Introduction

DeLancey proposed the hammock theory of urethral support in 1995 [1]. In his description he maintained that continence is the result of compression of the urethra and bladder neck by a hammock-like musculofascial layer. When this layer is deficient, funneling of the bladder neck during increased intra-abdominal pressures results in incontinence. The aim of the pubovaginal sling (PVS) is to restore the musculofascial support by reinforcing the urethra. This allows for kinking during times of increased abdominal pressure, thereby preserving continence.

Historical perspective

Although DeLancey described the hammock theory in 1995, the first description of treating stress urinary incontinence (SUI) with suburethral/bladder neck support occurred over 100 years ago. It was in Paris, in 1907, that Giordano first described using graft material, specifically gracillus muscle, as a urtheral/bladder neck sling to treat incontinence [2]. Later, in 1910, Goebell used pyrimidalis muscle to create this suburethral sling [3], and in 1933, Price used fasica lata as sling support of the urethra [4]. The process continued to evolve.

In 1978, McGuire and Lytton popularized the autologous fascial sling by reporting on their experience of 52 cases [5]. Their technique described the harvest and use of a 1 × 12-cm piece of rectus fascia to support the urethra. They had an 80% success rate at a mean follow-up of over 2 years. In the late 1990s, Blaivas modernized the procedure as he showed that all forms of SUI could be addressed with an autologous rectus fascial sling [6]. Prior to this, its application was limited to type 3 SUI only.

Diagnosis

Patients with SUI present with the complaint of involuntary urinary loss with increased intra-abdominal pressures, such as with coughing, laughing and Valsalva test. The diagnosis can be made based on history and physical examination alone, and quantified with a pad test. Attention should be paid to any associated prolapse, presence or absence of urethral hypermobility, symptoms of overactive bladder, urge incontinence, or significant postvoid residual (PVR) urine. The utility of urodynamic testing is debatable in the diagnosis of primary SUI; however, it is helpful in cases who are not as straightforward and in those complicated by the aforementioned pathologies, and it is required in recurrent SUI after failed surgery. In patients with associated vaginal prolapse, the SUI may be occult and become evident with the reduction of the prolapse. Patients with overactive bladder and or urge incontinence may not improve with a mid-urethral sling, and may actually get worse [7]. Finally, patients with PVR urine, depending upon its etiology, should be counseled regarding an increased risk of urinary retention after a sling procedure.

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Surgical indications

PVS is indicated in the treatment of SUI, whether from intrinsic sphincter deficiency or urethral hypermobility. Other indications include the treatment of incontinence after prolonged indwelling catheter drainage [8], incontinence after pelvic or urethral trauma [9] (where placement of synthetic mesh may lead to an unacceptably high rate of urethral erosion), and for continent support at the time of vesicovaginal fistula [10] or urethral diverticulum repair [11]. Finally, PVS can be used to augment continence after a bladder-neck reconstruction [12].

Of note, prior vaginal surgery is not an absolute contraindication to PVS; however, it can make the surgery technically challenging. Further, PVS can be done safely and effectively at the time of pelvic organ prolapse repair [13].

Surgical alternatives

The surgical alternatives to PVS for the treatment of SUI include transvaginal plication, retropubic suspensions, mid-urethral slings, artificial urinary sphincters, urethral bulking agents, and radiofrequency ablation. Nonsurgical therapies include pessaries, indwelling catheters, pads, and medical therapy.

Choice of material

The materials available to the surgeon for PVS are autologous tissue, allograft, xenograft, and synthetic meshes.

Synthetic meshes

The use of synthetic meshes obviates the need for autologous fascial harvest and thereby has the advantage of decreasing operative times. Also, as these are nonbiologically derived material, there is no risk of disease transmission. Furthermore, nonabsorbable meshes are not degraded like the biologic materials and maintain their strength over time. These advantages need to be weighed against the real risks of vaginal extrusion and urinary tract erosions. This is our material of choice and we use an off-the-shelf piece of prolene mesh that is cut into a strip measuring 2 × 7 cm.

Allografts

Like synthetic meshes, allografts do not require fascial harvest and similarly have the advantage of decreased operative times, decreased postoperative pain, and a shorter convalescence. Additionally, they are readily available as an off-the-shelf material that can be used as needed. Allograft materials have lower erosion and extrusion rates compared to synthetic meshes [14], but these advantages must be weighed against the higher cost of allografts compared to mesh, and the theoretical risk of disease transmission. Another potential disadvantage is that different allografts may have different biomechanical properties based on differences in cadaver harvest or tissue processing. Our allograft of choice is Tutoplast (Mentor Corporation, Santa Barbara, CA, USA), which is fashioned into a strip measuring 2 × 7 cm.

Xenograft

Commonly used xenografts for PVS include material derived from porcine dermis (Pelvicol; CR Bard Inc, Murray Hill, NJ, USA) or porcine small bowel (SIS™; CR Bard Inc). They are readily available as off-the-shelf materials that can be used as needed. These materials have the same disadvantages as allografts, particularly higher product costs, biomechanical variability, and a theoretical risk of disease transmission.

Autologous tissue

These are obtained, as the name implies, from the patients themselves. These tissues require more operative time to procure, and increase perioperative and postoperative morbidity and convalescence [15]. Furthermore, the quality and strength of the harvested autologous tissue is variable, depending on the patient's age, medical comorbidity, and previous surgeries. Despite these disadvantages, autologous tissues are the material of choice of many surgeons as they are completely biocompatible and have no risk of erosion or extrusion. The two most commonly used tissues are fascia lata and rectus fascia. Grafts using the anterior vaginal wall have also been described, but are discussed elsewhere.

Fascia lata

The use of fascia lata as a sling material was initially described by Price for sacral agenesis [4]. It was popularized as a material for suburethral slings in the treatment of incontinence by Beck *et al.* [16]. The theoretical advantages of fascia lata over rectus fascia are that fascia lata is less affected by previous abdominal surgery, patients with this sling material are less prone to abdominal wall hernias, and it has greater tensile strength. The disadvantages of fascia lata are the time required for harvest, harvest site pain/disability, need for patient repositioning, and the operative field is not one usually employed by urologists.

There are many different techniques to harvest fascia lata for use in PVS. Our preference has been to use the technique described by Govier *et al.* [17], which is outlined here. The patient is placed in the full lateral position with the entire thigh, from the iliac crest to the tibial plateau being prepped and draped into the surgical field. A vertical line is drawn from the greater tronchanter of the femur to the medial condyle of the knee. A 3-cm perpendicular incision is made at the mid point of this line. Two additional perpendicular incisions of 3 cm in length are made, flanking the first incision 9 cm superior and inferior (Figure 144.1). Via these incisions the fascia lata is cleared off from the overlying subcutaneous fat. At the three skin incision sites, incisions parallel to the direction of the fascial fibers are made 2.5 cm apart. At the distal and proximal ends of the fascia, two stay sutures are placed perpendicular to the fibers of the fascia and the fascial incisions are connected to free a piece of fascia lata approximately 24 cm in length and 2.5 cm in width. Hemostasis is achieved, the fascia lata is not approximated, and the skin is closed with a stapler. The leg is then wrapped with an elastic dressing, which is removed 8 h postoperatively, and early ambulation is required of all patients.

Rectus fascia

Rectus fascia is our autologous material of choice as it is in the surgical field and thus is easily procured. To obtain the sling, a low transverse abdominal incision is made. Dissection is carried down to the level of the anterior rectus fascia and the fascia is cleaned of overlying fat. The intended fascial incision is marked with a marker pen; the marked fascia should be 1 cm in width and 12 cm in length, noting the inferior portion is at least 5 cm from the pubic symphysis. Two stay sutures are placed at the distal ends of the fascia, perpendicular to the fascial fibers. With traction on the stay sutures, the fascial strip is then mobilized with a combination of sharp and blunt dissection (Figure 144.2). The defect in the fascia is then closed in a running fashion with delayed absorbable suture.

Preoperative preparation

In the absence of contraindication, estrogen cream is prescribed for 4–6 weeks pre-operatively in postmenopausal patients with vaginal epithelial atrophy. If the patient uses a pessary, it is discontinued 2 weeks prior to surgery. All forms of anticoagulation, including "baby" Aspirin, must be stopped with sufficient time to allow for normalization of bleeding parameters. Preoperative complete blood count, basic metabolic panel, coagulation studies, urinalysis and urine culture are obtained. In the presence of a urinary tract infection, coagulopathy or other significant medical abnormality, surgery is postponed. If constipation is present preoperatively, the patient is placed on an aggressive bowel regimen in the weeks preceding surgery. The patient is then made nil per mouth at midnight on the evening prior to surgery. Based on the American Urological Association (AUA) guidelines for surgical prophylaxis, a first- or second-generation cephalosporin is given intravenously in the anesthesia holding room at least 1 h prior to surgery and continued for a total of 24 h.

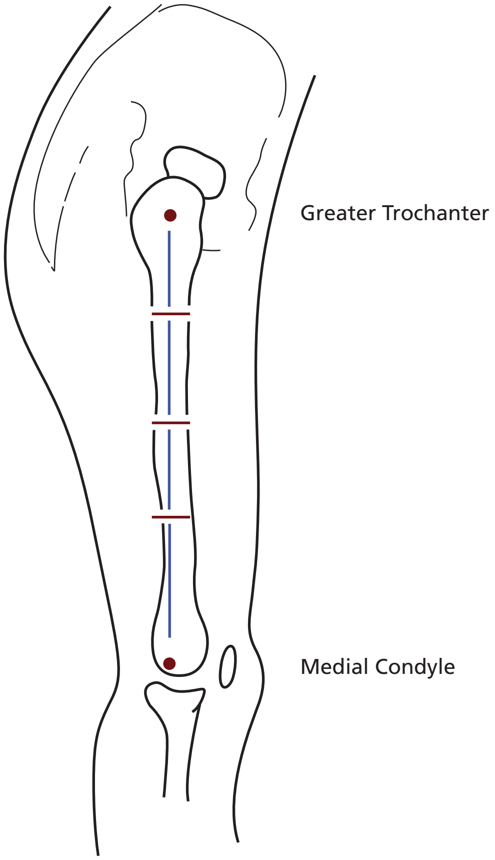

Figure 144.1 Skin incisions for fascia lata harvest.

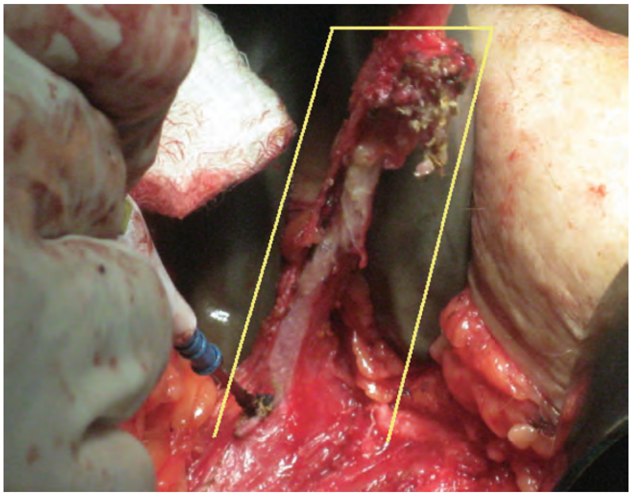

Figure 144.2 Rectus fascia sling mobilization.

Operative technique

Once moved to the operating table, sequential compression devices are placed on the lower extremities and general endotracheal anesthetic is induced. The patient is then positioned in the dorsal lithotomy position using Allen Yellofin stirrups. The abdomen, pubis, and perineal area are shaved using clippers and then prepped with chlorhexidine-based chemical antiseptic. The patient is then draped with the Lingeman Gyn surgery drape (Microteck Medical, Columbus, MS, USA). A 16F urethral catheter is placed in the urethra and the balloon is inflated to help facilitate identification of the bladder neck. A Lone Star surgical retractor is used to retract the labia and open the introitus for exposure. A weighted speculum is placed to retract the posterior fourchet.

An Allis clamp is placed at the hymen ring along the anterior vagina and ¼% bupivacaine (Marcaine) with epinephrine is injected from 1 cm proximal to the urethral meatus to the bladder neck, for hydrodistention. A 4-cm midline incision is made over the bladder neck with the Foley balloon used as a guide. Curved Metzenbaum scissors are used to dissect thick flaps of anterior vaginal wall epithelium in an anterolateral fashion, toward the ipsilateral shoulder, until the endopelvic fascia is reached. The Foley catheter and balloon should be constantly used as a guide to the urethra and bladder neck. The depth of dissection is marked by a "bloodless" plane. At this point, with either the curved Metzenbaum scissors or blunt finger dissection, the endopelvic fascia is perforated bilaterally. A packing sponge is placed in the vagina and attention is turned to the lower abdominal incision.

A 10-cm Pfannenstiel incision is made one finger breadth superior to the symphysis pubis. Using cautery, the dissection is carried through Camper's and Scarpa's fascia, and the anterior rectus fascia is identified. Using sharp and blunt dissection, the fascia is cleaned of the overlying fatty tissues. A scar-free area of the fascia at least 5 cm above the symphysis pubis is chosen (to aid in closure). As described above for procuring rectus fascia, the sling material is dissected such that a 12 × 1 cm rectus fascial sling is made. At the lateral aspect of the sling, the holding sutures are exchanged for 0-prolene sutures, with a figure-of-eight suture placed 0.5 cm from the lateral margin of the sling on each side. At the midline of the sling, using a surgical marker, a vertical line is drawn. The sling is then placed in a bath of normal saline with bacitracin antibiotic.

After ensuring complete decompression of the bladder, at 2 cm above the symphysis pubis, the lateral aspect of the rectus muscle is identified and retracted medially. The underlying transverse fascia is perforated bilaterally and connected to the vaginal incision. As this space is being developed with ether blunt or sharp dissection, it is important to stay directly on the posterior surface of the pubis to avoid injury to vessels or the bladder.

The sling is then placed in the anterior vaginal dissection and, using two long curved clamps, the holding sutures on the lateral aspect of the sling are brought to the abdominal incision through the tunnels created lateral to the rectus muscle. Hemostats are placed on each set of holding sutures laterally. A 4-0 Vicryl suture is used to fix the midline of the sling, previously marked, to the midline periurethral tissue at the bladder neck. The vaginal incision is closed with 3-0 PDS suture and an estrogen cream-soaked vaginal pack is placed in the vagina.

A tonsil clamp is used to make two perforations in the rectus fascia lateral to where the sling was procured. The holding sutures are tunneled through these openings ipsilaterally. The rectus fascia is then closed using 0 PDS sutures in a running fashion. The sling-holding sutures are tied to each other over the now closed fascial incision. The tensioning of the sling sutures is such that one finger should be able to be placed between the rectus fascia and the sling sutures in the midline before any movement of the bladder neck occurs. This is obviously one of the most important parts of the operation; as a sling that is too loose will result in continues incontinence and a sling that is too tight will result in retention. The skin is then closed with a 4-0 Monocryl suture.

Postoperative care

A complete blood count is ordered in the postoperative anesthesia care unit and in the morning of postoperative day 1. After reviewing the hemoglobin, on postoperative day 1 the vaginal packing and the catheter are removed and the patient is given a voiding trial. If there is significant residual urine, the patient is taught clean intermittent catheterization. At this point the patient is discharged home with stool softeners and oral narcotics. They are given explicit instructions to avoid vaginal penetrative intercourse and heavy lifting for 6 weeks. They return for follow-up in 6 weeks to assess postoperative results and voiding parameters.

Clinical results

Synthetic slings

A review of the literature regarding the uses of polypropelene mesh, our material of choice, as the sling material for PVS revealed a paucity of long-term studies. The two published large-volume, long-term studies (Table 144.1) report an overall cure rate for synthetic PVS (using polypropelene) of approximately 81% with over 90% being cured or improved.

Allograft slings

As allograft materials have become readily available, their use as a sling material in PVS has increased. As mentioned previously, the decreased morbidity and the decreased operative time associated with allograft slings compared to autologous slings make them a favorable choice. Published reports for allograft fascial slings in the last 10 years are shown in Table 144.1.

Xenograft slings

Xenograft slings have only recently become widely available for use in the USA. Although the number of published reports on their use as sling material in PVS is low, their short- and longer-term results appear promising (Table 144.1).

Autologous fascia

There are most studies and long-term results for the use of autologous tissues for sling material in PVS. The long-term results are good and they are often the benchmark to which other slings are compared (Table 144.1).

Complications

Intraoperative complications

Intraoperative complications such as bladder injury, urethral injury, bowel injury, and hemorrhagic complications from injury to blood vessels can all occur. Although serious injuries and mortality during PVS procedure are exceedingly uncommon, the surgeon must remain vigilant during and after the procedure to identify these problems and address them as they arise.

Table 144.1 Clinical results for different sling materials.

Study	Number of patients	Average length of follow-up (months)	Cure rate (%)	Improvement rate (%)d	Material
Synthetic slings					
Rodriguez *et al.* [20]	146	42		92	
Kuo [21]	64	24	81	97	
Allograft slings					
Onur *et al.* [22]	24	13	70 (no pads)	79	Dermis
Almeida *et al.* [23]	60	36	40	60	Fascia lata
Owens *et al.* [24]	25	15	32 (no pads)	68	Dermis
Walsh *et al.* [25]	31	14	93	N/A	Fascia lata
Soergel *et al.* [26]	12	3	33	N/A	Fascia lata
Elliot *et al.* [27]	26	15	77	92	Fascia lata
Amundsen *et al.* [28]	104	19	63	84	Fascia lata
Brown *et al.* [29]	121	12	74	83	Fascia lata
Xenograft slings					
Giri *et al.* [30]	51	36	N/A	54	Porcine dermis
Wilson *et al.* [31]	37	12	84	N/A	Bovine dermis
Arunkalaivanan *et al.* [32]	74	12	89	N/A	Porcine dermis
Autologous fascia					
Chaikin *et al.* [6]	251	37	N/A	92	Rectus fascia
Morgan *et al.* [33]	247	51	82	88	Rectus fascia
Sharifiaghdas *et al.* [34]	36	40	83	N/A	Rectus fascia
Govier *et al.* [17]	32	14	87	97	Fascia lata

N/A, not available.

Harvest site complications

These are associated with autologous fascial slings. They include harvest site hernias [18] and leg pain [17]. These complications are rare and are often reported as single cases in larger series. In the case of hernia, if symptomatic, surgical repair is indicated [18]. In the reported case of postoperative leg pain after a fascia lata sling, the pain resolved with physical therapy [17].

Persistent stress incontinence

Despite the high success rates of PVS, regardless of the material used, persistent stress incontinence can remain. When this occurs it is important to get an accurate assessment of the degree of leakage that is occurring by quantifying it. Furthermore, urodynamic evaluation is also important in ruling out urge incontinence and determining leak point pressures. Based on the degree of bother, pad usage, and leak point pressure treatments, including timed voiding, the off-label use of duloxetine, urethral bulking agents, or sling revision can be discussed.

De novo urinary urgency

This is a troubling problem after PVS. The incidence of postoperative *de novo* urinary urgency is variable and has been reported to occur in patients at a rate of 5–44% [19]. *De novo* urinary urgency often responds to anticholinergic medications. When this fails, other treatments, including pelvic floor rehabilitation, sacral neuromodulation, botulinum toxin, imipramine, may be considered.

Urinary retention

This is the result of anatomic or functional obstruction when the sling is tied with excessive tension. The rate of postoperative retention is variable, but in most studies it decreases with time, such that at a year less than 5% of patients have significant postoperative urinary retention [19]. In the immediate postoperative period, urinary retention is managed with clean intermittent catheterization. If it persists pasts 3 months, we perform urodynamic testing and if due to increased outlet resistance, incision of the sling is considered.

Urinary tract erosion and vaginal extrusion

These are feared complications of PVS. Based on a review of over 5000 articles by the AUA Guidelines Panel, the rate of extrusion and erosion for autologous and allograft PVSs was less than 1% [14]. The real concern for extrusion and erosion is with the use of synthetic materials. Earlier used synthetics had an unacceptably high rate of these serious complications. Fortunately, the contemporary use of prolene as synthetic mesh has not been associated with such high erosion and extrusion rates [20]. Most urinary tract erosions occur within 6 months of placement of the sling and often present with hematuria, infections, voiding dysfunction and/or urinary retention. When present, urinary tract erosion mandates removal of all exposed sling material. Vaginal extrusion can occur and often presents with vaginal discharge and/or patient or partner dyspareunia. The extent and bother of the extrusion dictates the treatment, which varies from topical estrogen creams, to segmental sling excision, or flapped vaginal closure.

Conclusions

The aim of the PVS is to restore the musculofascial support by reinforcing the urethra, which serves to restore continence in patients with SUI. Although there is a choice of using autologous, allograft, xenograft, and contemporary synthetic materials for slings, all have good results with acceptably low complication rates.

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CHAPTER 145

Mesh Kits for Vaginal Prolapse Surgery

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Introduction

There has indeed been a revolution in pelvic reconstructive surgery over the past decade. This revolution has occurred in large part due to the growing incidence of genital prolapse and other pelvic floor dysfunctions in women, as well as greater awareness from industry regarding the need for appropriate tools for use by pelvic reconstructive surgeons. As a result, new techniques, materials, and tools have become available and have been marketed widely. As with any rapidly changing medical field, progress has been associated with controversy as reported improved outcomes have been associated with new and yet poorly understood consequences of new approaches, materials, and techniques. In this chapter, we will discuss the evolutionary development of prolapse repair kits utilizing synthetic and biologic graft materials, their reported outcomes, and reported consequences.

Demographic changes in our population are mainly based on increased life expectancy. Thus, there will be an increased number of women with pelvic floor dysfunction presenting to physicians' offices over the next few decades. It has been estimated that the number of women with at least one pelvic floor disorder will increase from 21.8 million to 43.8 million between 2010 and 2050 [1]. The number of women with urinary incontinence will increase by 55% and the number of women with pelvic organ prolapse will increase by 46%, up to a total of 4.9 million women. This increase in prevalence of pelvic floor disorders can seem quite alarming and does require an increased understanding and knowledge of these disorders by clinicians caring for women with pelvic floor disorders. Traditional approaches to genital prolapse have been fraught with lower than acceptable success rates, particularly in the anterior compartment where success rates of less than 50% were frequently reported with traditional midline plication techniques. The evolution of prolapse surgery has followed along the lines of evolution in anti-incontinence surgery. Traditional compensatory procedures were deemed to have less than acceptable results and as a consequence new tools were developed to assist surgeons in their surgical procedures. A clear example is the development of more standardized approaches to stress incontinence, such as the tension-free vaginal tape (TVT) sling procedure, which represented the first kit approach to stress incontinence with a standardized, step-by-step technique. It did not take long for the popularity of the TVT sling procedure to lead to the development of analogous approaches to genital prolapse with standardized mesh and needle-based kits (Figure 145.1).

Thus, the onset of usage of graft kits for prolapse surgery follows a rather rational progression of technologic improvements. Some argue that this progression in new technology development has occurred too rapidly, without time to critically analyze its results and consequences, and thus controversy has arisen.

Who are the appropriate candidates for mesh kit implantation? This question has led to many discussions regarding the indications for mesh kit usage. With a lack of medium- and long-term comparative studies in different population segments, it is in fact difficult to

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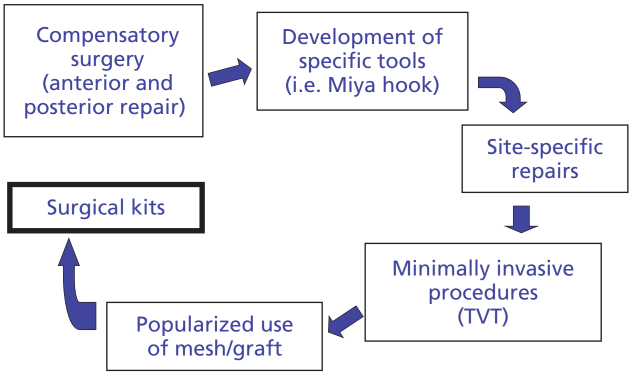
Compensatory surgery (anterior and posterior repair)
Development of specific tools (i.e. Miya hook)
Site-specific repairs
Minimally invasive procedures (TVT)
Popularized use of mesh/graft
Surgical kits

Figure 145.1 Evolution of prolapse surgery. TVT, tension-free tape.

clearly distinguish those patients who may significantly benefit from the mesh kit repair. As experience grows with the use of mesh kits, the risks associated with synthetic mesh kit use have become more apparent and the risk-to-benefit ratio has become clearer. We will discuss this further in this chapter. One thing is likely clear. The failure rate of recurrent prolapse surgery repair is greater than that found with primary prolapse repairs [2]. Thus, patients with recurrent prolapse, especially those with weak fascia or large fascial defects, may particularly benefit from mesh reinforcement during prolapse surgery. Among other accepted indications are patients with chronic increases in intra-abdominal pressure and those with endogenously weak supportive tissues.

Synthetic mesh is used to recreate supportive ligaments (such as with suburethral slings) and replace missing or defective fascia along the anterior and posterior walls. Biologic grafts are typically not of sufficient integrity and strength to replace fascia and thus are primarily utilized to reinforce weakened fascia, such as an overlay to a midline plication of the patient's endogenous fascia. These different applications of synthetic versus biologic grafts are being more clearly understood as published clinical series report differences in outcomes.

Benefits of prolapse repair kits

These include:

- *Standardized surgical procedures.* A standardized, step-by-step procedure allows for quarter predictability of outcomes when a procedure is performed by different surgeons.
- *Comprehensive prolapse repairs.* Repair of apical, anterior, and posterior vaginal prolapse within one surgical procedure is beneficial to the patient by reducing the likelihood of opposite compartment prolapse. The likelihood of sequential surgeries to repair subsequent prolapse is also likely reduced.
- *Time efficiency in the operating room.* Standardized techniques with subfascial dissection have been reported to result in simplified surgeries with greater reported time efficiency and reduced costs.

These theoretical benefits of synthetic mesh kits are associated with concerns regarding the growing widespread implantation of these kits:

- *Patient selection.* Identification of appropriate patients for mesh repairs is crucial to achieving the above desired benefits. The surgeon must thus have sufficient knowledge of anatomy and identification of anatomic defects on physical examination in order to appropriately select patients for kit repairs.
- *Surgeon skills and knowledge.* An unskilled surgeon armed with a surgical kit will still likely have suboptimal outcomes. Thus, surgical kits do not make up for poor surgical technique and skills.
- *Material choices.* Experience has taught us that Type 1 polypropylene mesh (monofilament, macroporous) is the only type of mesh that should be utilized in the pelvis in order to minimize the chances of infection, inflammatory changes and biofilm formation (see Chapter 143). However, within Type 1 mesh materials there are variations in composition and construct, thus leading to a need for greater definition in terms of outcomes based on different types of Type 1 mesh.
- *Complications.* As with any surgical technique, complications are reported with a novel technique. There are indeed specific complications related to synthetic mesh kits. These will be discussed further in this chapter. However, it must be stated that the benefits of kit use should far outweigh any reported complications.
- *Long-term effects.* As with any new surgical technique involving a permanent implant, the greatest concern arises from the long-term impact of a synthetic implant on a patient's quality of life and anatomy. Only time will tell whether there are any significant adverse effects noted years remote from implantation of a synthetic material in the pelvis. Major long-term concerns relate to vaginal anatomy and its impact on sexual function. Specifically, the impact of estrogen deprivation after menopause and stiffening/contraction of mesh may result in long-term sexual dysfunction and possibly difficult-to-treat erosions.

Currently available kits

There are a number of mesh kits currently available for repair of vaginal prolapse. These kits fall into two primary categories.

Trocar-based kits rely on transobturator or transgluteal passage of needles to implant the mesh arms onto the desired anatomic locations (Figure 145.2). These kits include:

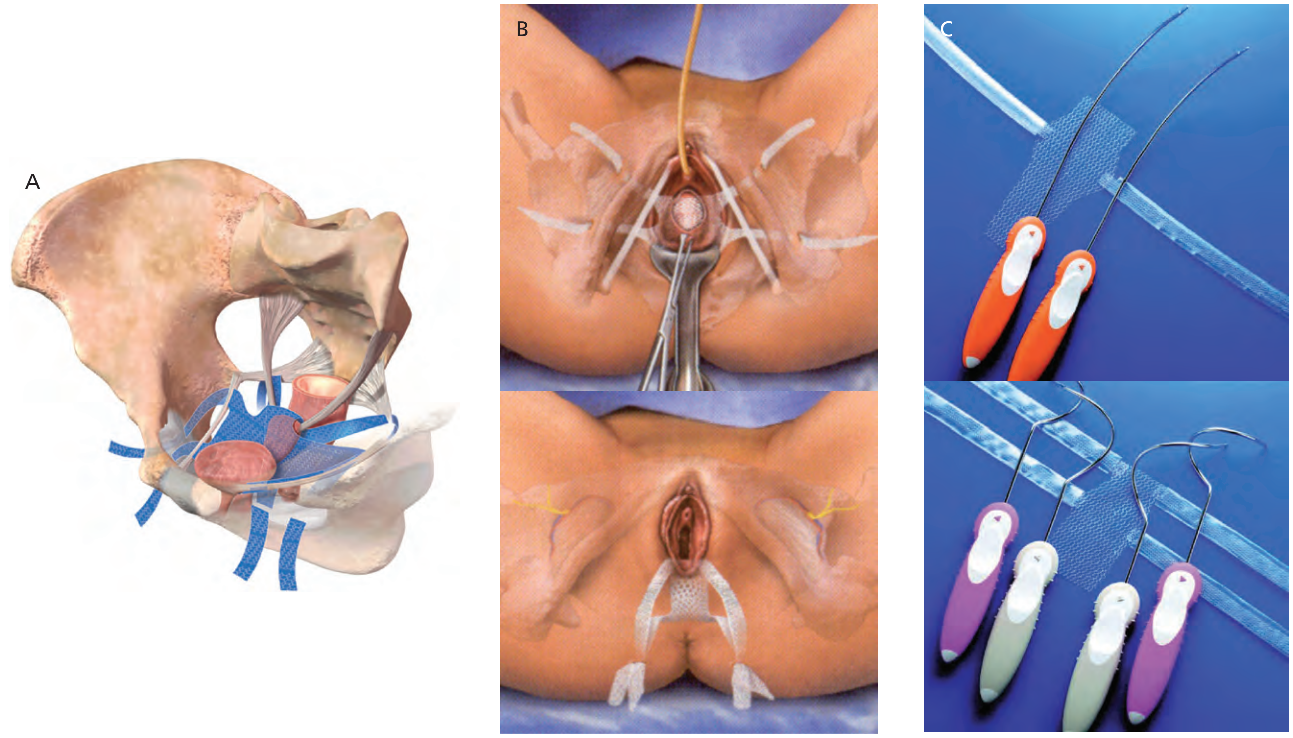

Figure 145.2 Trocar-based mesh kits. (A) Prolift (reproduced courtesy of Ethicon Women's Health & Urology, Somerville, NJ, USA; © ETHICON, Inc. Reproduced with permission.); (B) Avaulta anterior posterior (courtesy of CR Bard Inc, Murray Hill, NJ, USA); (C) Apogee/Perigee (courtesy of American Medical Systems Inc, Minnetonka, MN, USA).

- Prolift: anterior and posterior (Gynecare; Ethicon Women's Health & Urology, Somerville, NJ, USA);
- Apogee (apical and posterior wall) and Perigee (anterior wall) (American Medical Systems Inc, Minnetonka, MN, USA);
- Avaulta anterior and posterior (CR Bard Inc, Murray Hill, NJ, USA).

Internal fixation kits rely on internal fixation onto soft tissue structures without the use of external perineal or perianal incisions (Figure 145.3). These kits include:

- Soft tissue anchor based system: Elevate anterior and posterior (American Medical Systems Inc);
- Pulley suture based systems: Pinnacle and Uphold (Boston Scientific Corporation, Natick, MA, USA).

Composite kits that do not rely solely on Type 1 mesh material incorporate other biologic materials along with the synthetic Type 1 mesh:

- Synthetic tape with biologic non-cross-linked porcine dermal anterior and posterior capes: Apogee and Perigee (American Medical Systems Inc) (Figure 145.4);
- Collagen coating on synthetic polypropylene mesh: Avaulta Plus (CG Bard Inc).

Other kits are also available which are not as widely marketed. These include a prepubic and transobturator placed anterior mesh kit, Nazca TC (Promedon, Cordoba, Argentina); other trocar-based made kits, Ascend (Caldera Medical Inc, Agoura Hills, CA., USA), as well as self-made polypropylene mesh kits used by individual surgeons. Overall, the synthetic polypropylene mesh kits rely on subfascial dissection and fixation to either the sacrospinous ligaments (Prolift posterior, Elevate anterior and posterior, Avaulta posterior, Pinnacle, and Uphold) or soft tissues anterior to the ischial spine at the level of the attachment of the arcus tendineus (Apogee) or obturator membrane and paravaginal support tissues (Perigee, Avaulta, Nazca).

Reported outcomes

As the time of writing, no specific published reports were identified on Avaulta, Pinnacle, Uphold or Nazca.

Prolift

Numerous publications over the past few years have documented expected outcomes with the use of the synthetic Prolift kits for vaginal prolapse. Table 145.1 describes the most commonly reported findings. A large number of subjects have been included in these studies with follow-up of longer than 1 year in many [3–8]. A combination of anterior, posterior, and combined Prolift kits has been utilized with success rates ranging from

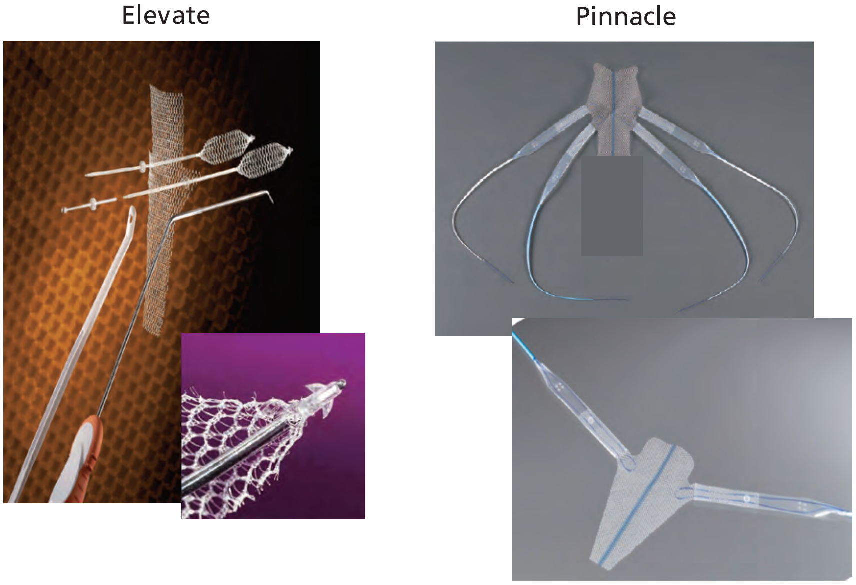

Figure 145.3 Elevate (courtesy of American Medical Systems Inc, Minnetonka, MN, USA) and Pinnacle (courtesy of Boston Scientific Corporation, Natick, MA, USA) internal fixation-based kits.

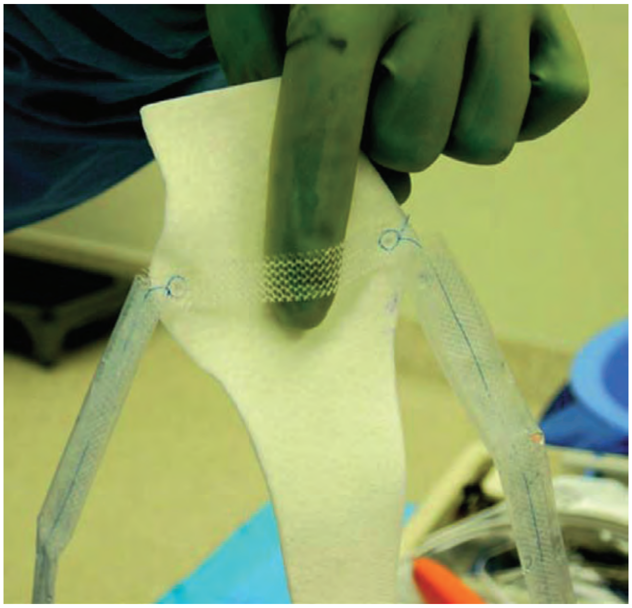

Figure 145.4 Composite synthetic–biologic kit.

87% to 95%. Complication rates have been reported and will be reviewed in the subsequent section. Overall, the Prolift kit has the longest track record, having been initially described as a total vaginal mesh (TVM). It was developed in France, with outcomes reported on a serial basis by its originators. This group first reported on the original 794 patients (684 TVM and 110 Prolift) [3]. The main changes in construct of the kit involved a softer Prolene mesh as well incorporation of a user-friendly kit with simple-to-use trocar cannulas. This French group also reported on expected outcomes. They noted a significant reduction in erosion rates when a hysterectomy was not performed and thus advocated for uterine preservation with performance of a prolapse repair. In addition, they reported a significantly greater increase in erosion rates when a T-incision was used for the performance of a hysterectomy and anterior prolapse repair. If a hysterectomy is performed, they suggested a linear incision rather than a T-incision for the cuff/anterior vaginal wall.

Perigee/Apogee

Of these two kits, Perigee has been reported on to a greater degree. The synthetic Perigee kit for repair of cystocele was the focus of a recent 2-year follow-up prospective multicenter trial reporting a success rate of 88.5% [9]. This group reported an extrusion rate of 10.5% and pelvic pain in 4.4% of subjects. An earlier report by Garauder-Burmester *et al.* from Berlin reported on the combined use of Apogee and Perigee for women with recurrent vaginal prolapse [10]. They reported a cure rate of 93% and a 7% anterior compartment level 2 prolapse recurrence rate. The total vaginal length was 7.6 cm. They reported a 3% erosion rate, all in the anterior compartment. Importantly, they reported no *de novo* dyspareunia. In a very well-designed and executed randomized controlled trial with 1 year follow-up, Nguyen and Burchette reported on synthetic Perigee versus anterior colporrhaphy for women with anterior vaginal prolapse [11]. The Perigee arm had a significantly higher success rate (89% vs 55%), and the dyspareunia rate was very low (16%) in both the Perigee as well as the traditional anterior colporrhaphy groups. Treatment of vaginal vault prolapse with the Apogee kit has been the subject of a multicenter trial reported by Lukban *et al.* in a series of 200 patients with a follow-up of 8.6 months [12]. They reported a cure rate of 92.2% with an operative time of 45.8 min. This group included synthetic and biologic Apogee kits; the cure rate with the synthetic Apogee kit was 93.3% and the apical sure rate with the biologic Apogee kit (with synthetic apical tape) was 97%. The rate of erosions was 7% and that of dyspareunia was 1%. We reported on our experience with biologic Apogee (with the synthetic arm at the apex) in 104 patients with a follow-up of 28.9 weeks [13]. We found an apical failure rate of 3.8% with an anterior compartment recurrence rate of 14.4%. These patients did not undergo kit anterior wall repair. The total vaginal length was 8.1 cm and *de novo* dyspareunia occurred in 9%.

Elevate anterior and posterior

This new internal fixation kit has been the subject of a recent multicenter trial. Six-month data were reported in abstract format, revealing cure rates of approximately 95% with a 1.5% incidence of buttock pain [14]. Clearly, longer-term reports are required to better analyze this novel technique.

Self-made kits

Cystocele repair via a transobturator passage with Surgipro™ mesh (Covidien, Mansfield, MA, USA) was reported by Eboue *et al.* in 113 patients with 1-year follow-up. An erosion rate of 6.5% was found with a failure rate of only 2% [15].

Complications

As with any novel, widely marketed surgical technique, controversy has resulted, especially as related to reported complications of vaginal mesh usage. The fact that anatomic outcomes are improved over traditional repair (especially in the anterior compartment) is fairly well accepted by the pelvic surgical community. However, complications have been reported and have lead to concerns regarding appropriate indications and reporting of complication rates, and to discussions regarding regulatory requirements prior to marketing of a novel implant (the US FDA 510K process for new product approval). Much of the controversy and debate has been emotionally based as there are insufficient data have to make educated statements about the actual complication rates expected with vaginal mesh usage. In fact, the developers of the TVM/Prolift kit reported that, in their opinion, complications of vaginal meshes are often overestimated, sometimes over emphasized, and often poorly described and managed [16]. In their compilation of Prolift cases (1882 interventions), complications included mesh exposition (12%), prosthetic contraction (17%), and *de novo* dyspareunia (9%). The reader will have their own opinion about whether these are high, low or expected rates.

Dyspareunia

Functional sexual disorders can have a markedly negative quality-of-life impact on a patient. Reported dyspareunia rates with synthetic kits have ranged from 0% to 18%. Perhaps most important is the *de novo* dyspareunia rate in a subject who has had normal sexual function prior to her prolapse repair. Lowman *et al.* focused on sexual function after Prolift and reported a 16.7% dyspareunia rate [17]. Other series have reported lower rates of 4–5 % (see Table 145.1) and as low as 0% in one series [10].

Mesh erosions

With non-Type 1 mesh tapes such as the intravaginal sling (IVS) (Surgipro™; Covidien), ProtoGen and ObTape, lack of incorporation of the graft was likely due to its multifilament, microporous nature. These ero-

Table 145.1 Reported outcomes for Prolift.

Study	Number of patients	Follow-up (months)	Anterior (%)	Posterior (%)	Total (%)	Success rate (%)	Erosion rate (%)	Dyspareunia rate (%)*
Fatton *et al.* [4]	110	3	20	26	54	95.3	4.7	
Milani *et al.* [5]	46	12			100	91	15	18
Feiner *et al.* [6]	100	12	100			87	10	5
Wetta *et al.* [7]	50	12	16	16	18	73	2	4
Aungst *et al.* [8]	335	8	20	8	71	94.8	3.8	5.5

**De novo* dyspareunia.

sions were much more concerning and frequently associated with infection, granulation tissue formation and biofilm development. Currently used meshes (Type 1 macroporous, microfilament) are not associated with this phenomenon. Therefore, most "erosions" present along the suture line and are likely due to a defect in the healing process along this line, due to suture line separation and/or hematoma formation. Reported erosion rates range from 2% to 25% (see Table 145.1). Local therapy with antibiotics and vaginal hormones can lead to resolution in up to 44% of cases [18], and therefore local estrogen therapy should precede any surgical therapy. It has also been found that commercial kits are associated with a lower erosion rate compared to self-fashioned mesh augmented vaginal repairs (11% vs 23.6%) [19].

Overall, mesh erosions should be handled rather conservatively. There is no need to remove the entire implanted mesh as the mesh is not being rejected or infected. Removal of the exposed mesh with mobilization of the adjacent vaginal epithelium and closure of the mesh defect, followed by tension-free closure of the vaginal epithelial defect under hemostatic conditions, should result in resolution of mesh erosion/exposure in the vast majority of cases.

Mesh contraction or shrinkage

This represents one of the most significant potential consequences of mesh implantation and emphasizes the importance of tension-free implantation of synthetic mesh. An average shrinkage of 25–30% has been reported after implantation in humans. An experimental abdominal wall rat model has shown a shrinkage rate of up to 40% [16]. In a recent series, Finer and Maher reported on 17 patients with mesh contraction; all patients presented with dyspareunia and focal tenderness over the contracted portions of the mesh. Mesh erosion as well as tightness and shortening of the vaginal canal were present in a significant number of cases. After mobilization of the mesh from underlying tissue, division of fixation arms and excision of contracted mesh, 88% of patients reported a substantial reduction of vaginal pain and 64% a substantial reduction in dyspareunia [20]. It is thus clear that the postoperative occurrence of vaginal pain and/or dyspareunia must be discussed with patients during the preoperative consent process, as a small, yet significant, percentage of patients will require surgical intervention to alleviate any problematic erosion and/or pain.

De novo stress incontinence

This has primarily been studied in anterior compartment mesh kits. If a sling is *not* performed in stress-incontinent women undergoing anterior mesh kit repair, cure of the stress incontinence is reported to occur in between 69% and 87.5% of patients [21, 22]. In previously continent patients, a *de novo* stress incontinence rate of 21% has been reported [22]. Therefore, preoperative prolapse-reduction urodynamic testing should be performed in order to identify patients with potential stress incontinence. Most surgeons would recommend performing a concomitant stress incontinence procedure at the time of kit mesh repair. If a sling is not performed, the likelihood of subsequent *de novo* stress incontinence should be discussed with the patient, as well as the potential need for a subsequent sling procedure as an outpatient.

Prolapse recurrence

Overall, prolapse recurrence rates with synthetic kit use are relatively low, ranging from 5% to 20%. These recurrences typically occur as apical or apical anterior recurrences due to detachment of the synthetic mesh from the apical attachment at the sacrospinous ligament, ischial spine or other supporting structures. It must be noted that the deeper dissection required for these mesh repairs leads to a typical appearance of a recurrent prolapse. This typical appearance entails an apical enterocele with no underlying endopelvic fascia. Therefore, a subsequent vaginal mesh procedure would be quite difficult. In our experience, an apical recurrence following a synthetic mesh kit repair will require an abdominal sacrocolpopexy in order to effectively repair the prolapse. During this procedure, we will incorporate the suspending mesh to the most superior edges of the implanted mesh anteriorly and posteriorly in order to recreate support integrity to the vaginal canal. This can be quite troublesome in an elderly patient in whom the abdominal procedure may have significant associated morbidity.

Bladder perforation

Bladder perforation during performance of a kit procedure has been reported to occur in 2–3.4% [23, 24]. This complication should be readily identified on cystoscopy intraoperatively. Therefore, the need for cystoscopy after passage of the anterior trocars is imperative and should be performed prior to connection of the mesh. In advanced prolapse repairs with mesh kits, cystoscopy as well as a rectal examination should be performed routinely to identify any visceral damage.

Other complications

These include fistula formation as well as hematoma [25, 26], which are associated with any reconstructive or needle-type vaginal procedure. They do not appear to occur in any greater percentage of cases with mesh kits compared to currently used sling procedures.

Future prospects in mesh kit utilization

There is currently much biomechanical engineering work directed at optimizing the construct of synthetic meshes implanted for the treatment of vaginal prolapse. The ideal mesh is yet to be identified. However, current advances in the construct of Type 1 mesh material with lighter, larger pore meshes are a demonstration of improvements in the science of this area of surgery. The future holds for lighter meshes with wider weave and less voluminous construct. It is likely that nonpermanent grafts will be developed, which will enhance deposition of a new and stronger endogenous collagen. The move towards internal fixation of supportive grafts is seen quite positively. It is likely that improvement in soft tissue fixation mechanisms will lead to greater longevity of meshes and less likelihood of detachment from apical supporting structures.

Currently, it appears fairly clear that mesh kits are here to stay. The growing need for durable repair of vaginal prolapse has led to increased bioengineering efforts at developing the ideal kit and suspensory materials. For now, surgeons should focus their efforts on careful selection of patients who may benefit from a prolapse kit, as well as improving their surgical skills in order to minimize complications related to kit usage. The preoperative consent process, informing patients of the risks, benefits, and possible complications of mesh usage, remains a crucial element in the care of women with advanced genital prolapse.

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CHAPTER 146

Male Slings for Treatment of Post-Prostatectomy Incontinence

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Epidemiology

Prostate cancer is the most prevalent malignancy among men in the USA, and surgical options include radical prostatectomy, performed using the retropubic or robot-assisted laparoscopic approach. Oncologic outcomes are overall favorable, and much attention has been paid to quality of life among men treated surgically for prostate cancer. Post-prostatectomy urinary incontinence is bothersome to patients, and varies in prevalence depending on the center and also due to the lack of a standardized definition of incontinence [1]. However, reported continence rates at high-volume centers are as high as 91–98% and may reach 95% after 1 year [2, 3]. Rates may vary by surgical technique, but also by patient demographics. It is reported that men younger than 50 years old are overall less likely to develop post-prostatectomy incontinence than men older than 70 [4].

Pathophysiology of male continence and post-prostatectomy incontinence

In the male, two sphincteric mechanisms work in concert to provide urinary continence. The proximal sphincter, comprised of smooth muscle fibers at the bladder neck extending to the bulbar urethra [5], is under autonomic control, while the distal sphincter is comprised of both striated and smooth muscle fibers extending from the verumontanum to the bulbar urethra [6], and is innervated by both unmyelinated autonomic and myelinated somatic nerves [7]. Magnetic resonance imaging (MRI) and cadaveric dissection studies have demonstrated the length of the distal sphincter to range from 1.4 to 2.4 cm [6, 8, 9]. The smooth muscle fibers of the distal sphincter lie internal to the striated fibers and are contiguous with the smooth fibers of the proximal sphincter [5]. Myers suggests this complex, known as a rhabdosphincter, should be thought of as the “sphincteric urethra” (Figures 146.1 and 146.2) [6, 10]. In the physiologically normal male, the proximal sphincter is responsible for providing resting continence.

Urinary incontinence following surgical prostatectomy may be influenced by a variety of factors, including insufficient sphincteric activity, detrusor overactivity, or anatomic abnormalities involving the bladder or vesicourethral anastomosis [11]. In patients who undergo surgical prostatectomy, destruction of the proximal sphincteric mechanism may occur. Many of these patients retain urinary continence solely by action of the distal sphincteric complex. At rest, this is maintained by apposition of urethral tissues, and resting tone provided by smooth and striated fibers within this sphincteric complex. In response to increases of abdominal or detrusor pressure, and during voluntary inhibition of flow in these patients, voluntary activity of the rhabdosphincteric fibers may occur, in conjunction with associated contraction of levator ani fibers, in order to maintain urinary continence [11, 12]. Stress urinary incontinence (SUI) related to deficiency of the external sphincteric mechanism is the most frequent type of incontinence following radical prostatectomy. Several studies have demonstrated urodynamic evidence of intrinsic sphincter deficiency (ISD) in the majority of patients with post-prostatectomy incontinence, ranging from 83–90%

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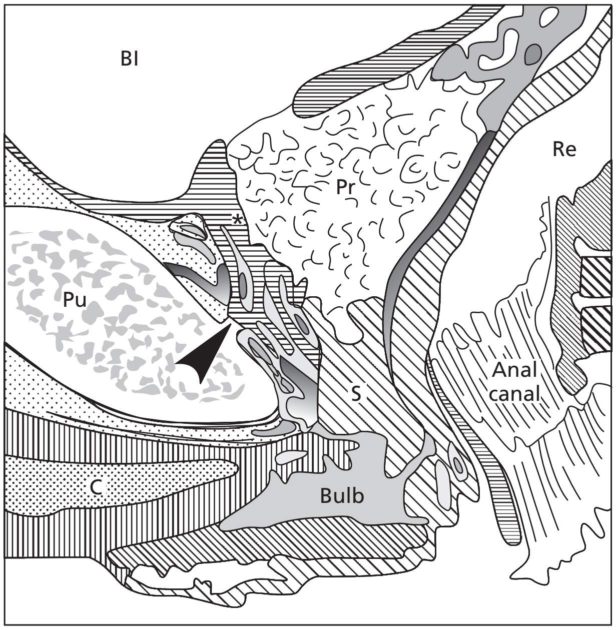

Figure 146.1 Structural anatomy of the striated urethral sphincter (s) and spatial relationship to the prostate (Pr), bladder (Bl), pubis (Pu), pubovesical ligament (arrowhead), bulbous urethra (Bulb), corpus cavernosum (c). Re, rectum. (Used with permission of Mayo Foundation for Medical Education and Research.)

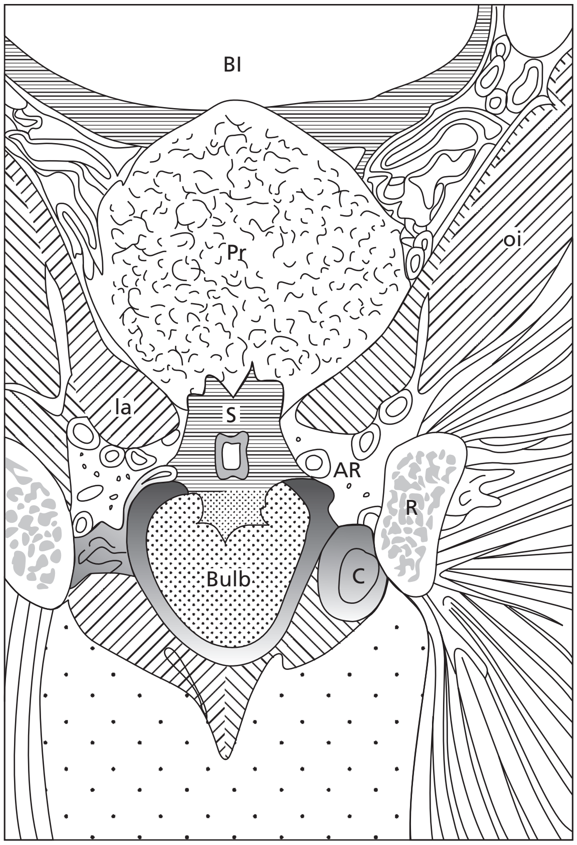

Figure 146.2 Structural anatomy of the striated urethral sphincter (s) and spatial relationship to the prostate (Pr), levator ani (la), bulbous urethra, corpus cavernosum (c), ischiopubic ramus (R), and anterior recess of ischioanal fossa (AR). Bl, bladder. (Used with permission of Mayo Foundation for Medical Education and Research.)

[13–15], this is the only urodynamic finding to account for incontinence in 60% of patients [16]. Thus, clinical and urodynamic evidence supports SUI caused by sphincter deficiency as the most common cause of post-radical prostatectomy incontinence. It is important, however, to note that transient urodynamic detrusor overactivity may be experienced in 2–77% of men following radical prostatectomy and may persist for up to 1 year [2, 17, 18]. In others with bladder neck contracture and who are incontinent following prostatectomy, an overflow pattern may be present.

Management

Continence following radical retropubic prostatectomy is recognized to increase over time. In the initial postoperative period, reassurance and psychologic support, as well as conservative therapy, including pelvic floor muscle strengthening exercises, timed voiding, and avoidance of dietary bladder irritants, may be helpful. Randomized prospective trials have reported quicker return to continence in patients who have undergone pelvic floor strengthening exercises [19, 20]; however, others have reported that this has not been true for patients with severe incontinence and does not extrapolate to long-term continence outcomes [21]. Additionally, patient factors including age, comorbidity, and preoperative voiding dysfunction, as well as neurovascular bundle preservation during prostatectomy, may influence postoperative return to incontinence.

Serial evaluation of urinary incontinence should be performed at regular follow-up visits during the first year after prostatectomy. Among patients who have persistent post-prostatectomy incontinence, many will consider surgical therapy. The artificial genitourinary sphincter (AGUS) was introduced in 1973 [22] and in its current form, the AMS 800 AUS (American Medical Systems, Minnetonka, MN, USA), has been associated with high success rates (61–96%) [23, 24] and minimal morbidity in appropriately selected patients [25]. It has long been the standard of care for surgical treatment of post-prostatectomy SUI.

Male urethral sling

The male urethral sling has recently been increasingly used for the treatment of mild-to-moderate post-prostatectomy SUI. Placement of a male urethral sling was first described in 1998 by Schaffer *et al.*; they placed

Dacron bolsters beneath the bulbar urethra and anchored these to the abdominal rectus fascia [26]. Since that time, a variety of mechanisms have been employed by which to apply passive external urethral compression with male slings. The rationale for using male urethral slings for post-prostatectomy incontinence is that, like the AGUS, their placement is minimally invasive. They are, however, less expensive than AGUS devices, and unlike the AGUS, slings provide fixed urethral resistance and/or repositioning that potentially enables better physiologic voiding [27]. Surgical treatment of male stress incontinence with urethral slings raises the question of *de novo* obstruction or associated urodynamic changes. This question was evaluated by Davies *et al*. who performed baseline and 3-month postoperative urodynamic testing on 13 patients undergoing placement of AdVance® (American Medical Systems Inc) male urethral slings for post-prostatectomy incontinence. At 3 months postoperatively, Valsalva leak point pressure (VLPP) significantly improved from 29.3 to 46.6 lb ($P = .03$), but there was no difference in baseline and postoperative detrusor voiding pressure, maximum or average flow rates, or postvoid residual (PVR) volume [28].

Bone-anchored slings

Comiter *et al*. first reported using male bone-anchored urethral slings in 2002 [29]. The commercially available InVance® system (American Medical Systems Inc) uses a disposable battery powered applicator to drive 5-mm self-tapping titanium screws into bone of pubic rami with preattached 1 Prolene suture. This anchors a pliable mesh sling composed of silicone-coated knitted multifilament polyester known as InteMesh® (American Medical Systems Inc). The mesh is porous, allowing for tissue ingrowth. The InVance system is designed for compression of the sphincteric urethra.

Several groups have reported success rates using InVance bone-anchored male urethral slings. Fassi-Fehri *et al*. reported outcomes at a mean of 6 months following InVance sling placement for post-prostatectomy incontinence. In their cohort, 50% of patients were dry (no pads), 26% improved (only 1 pad/day), and 25% had treatment failure. Overall success was 75%, and success was less likely in patients who had either severe urinary incontinence or a history of pelvic radiation. Success as defined by cure or improvement of incontinence was more likely in patients who had mild (90%) or moderate (76%) urinary incontinence. These authors speculate that periurethral fibrosis may contribute to failure in patients who have had radiation therapy [30]. Similar results with the InVance bone-anchored sling were found by Rajpurkar *et al.* who reported higher success using InVance slings in men with mild (83%) incontinence than in those with severe (50%) incontinence [31]. Immediate and intermediate continence results using InVance slings were recently reported by Guimaraes *et al*. who noted cure of incontinence in 70% of patients at 3 years and 66% at 4 years, as defined by wearing no pads [32]. Improvement as defined by requirement of less than half the pretreatment number of pads was noted in 20% by 3 years. In the short term, cure was noted in 67%, improvement in 25%, and failure in 8% of patients. Additionally, prevalence of minor complications in this interval was also reported among this group of patients and included transient elevated PVR volumes in 10%, sling explanation in 3% due to infection, and revision in 2% due to bone anchor dislodgement.

Some concern has been raised concerning bone infection in the setting of bone anchors. The risk of this has been examined in the female reconstructive literature and its prevalence is as low as 0.6% [33]. To date, no bony infections have been reported in males who have undergone placement of bone-anchored slings, possibly owing to lack of the vaginal flora encountered in female transvaginal surgery.

Long-term results with the InVance bone-anchored sling were recently reported by Carmel *et al* [34]. In that report, 45 patients with post-prostatectomy incontinence underwent InVance sling placement along with regular 2, 6, and 12 month, and yearly follow-up including pad testing, urodynamics, history, and UCLA/RAND and American Urological Association (AUA) symptom score data for a median follow-up of 36 months: 36% of patients were dry, 40% improved, and 24% reported failure. The vast majority of patients (86%) considered themselves cured or almost cured, and 72% were satisfied or very satisfied with the procedure. Complications were temporary perineal numb sensation lasting 1–3 months in 22%, temporary urinary retention in 7%, overactive bladder in 4%, *Clostridium difficile* colitis in one patient, and mesh infection resulting in removal in one patient. Similarly, a recent French multicenter study described treatment success and predictors of failure among 84 patients treated for incontinence with InVance male slings. In this study, at a mean of 20 months, 45% of patients were dry, 26% improved, and 29% had treatment failure. Univariate analysis identified three features as predictors of treatment failure: severe urinary incontinence, urodynamic instability, and a history of bimodal therapy for prostate cancer including radiation therapy. Failure rate was 67% if two or more of these factors were present versus 25% if one or none was present ($P = .013$) Bimodal therapy was the sole independent predictor of failure in multivariate analysis in this study [35]. Fischer *et al*. used a risk analysis model to predict success in 62 men treated for post-prostatectomy incontinence with bone-anchored slings and found that among several factors [time from treatment causing incontinence, age, abdominal leak point pressure, pad weight testing, maximum bladder capacity, detrusor overactivity, International Prostate Symptom Score (IPSS), and urinary distress inventory (UDI-6)] only preoperative pad weight of less than 423 g/day was a predictor of success. Patients with less than 423 g/ day leakage had a 71% chance of success and were six times more likely to have success as defined by perception of very much or much better on Patient Global Impression of Improvement (PGI-I) questionnaires [36].

Transobturator slings

Whereas bone-anchored male slings function by fixed urethral compression, transobturator slings were subsequently developed based on the concept of proximal relocation of the sphincteric urethra. Rehder and Gozzi described a novel technique for placement of a polypropylene tape beneath the bulbar urethra using the transobturator approach in a series of four cadaveric as well as 20 human male patients [37]. The middle part of the tape was fixed distally to the bulb and proximally to the perineal body, and when tension was applied to the ends of the tape, the proximal anterior urethra was relocated proximally by a distance of 3–4 cm, effectively lengthening the membranous urethra. Baseline and postoperative video urodynamics in the clinical series confirmed that at rest, the bladder neck and posterior urethra were more occluded, and the bladder neck was closed and more elevated than at baseline. Additionally, postoperative video urodynamics demonstrated a more elongated membranous urethra during micturition, having increased from a mean of 3 mm to a mean of 17 mm following placement of the tape. Urethral pressure profilometry in the same series demonstrated an improvement of supine mean urethral closing pressure at rest from 13.2 cmH_2O preoperatively to 86.4 cmH_2O postoperatively.

The rationale for treating post-prostatectomy male incontinence by transobturator tape is based on the theory that post-prostatectomy men with partially intact external sphincteric complexes may develop incontinence due to urethral hypermobility, resulting in urethral or perineal descent from the pelvis, possibly associated with coexistent levator laxity; hence proximal relocation of the sphincteric urethra may result in improved continence [37, 38].

Gozzi *et al*. reported continence results among 67 post-prostatectomy patients treated with transobturator urethral slings [39]. At 3 months postoperatively, 52% were cured (no pads) and 38% had improvement of incontinence (1-2 pads/day). Complications included persistent incontinence requiring sling replacement in five patients (7%), suprapubic drainage for postoperative retention in 11 patients (16%), and subsequent placement of AGUS in two patients (3%). A recent prospective multicenter trial by Cornel *et al*. examined pad weight test results at 3 months and 1 year following AdVance (American Medical Systems Inc) transobturator sling suspension in 37 men with post-radical retropubic prostatectomy (RRP) and post-transurethral radical prostatectomy (TURP) incontinence [40]. The overall cure rate was 14.3% at 3 months and 9% at 1 year. Improvement was noted in 42.8% at 3 months and 36.5% at 1 year. Pad testing demonstrated worsening incontinence in 14.2% of patients postoperatively. Additionally, urinary bother recorded by VAS was improved at 3 months postoperatively, but was not significantly different at 1 year. VAS score correlated with objective cure or improvement on pad weight testing. Interestingly, cure as defined by pad weight testing occurred only in the RRP group, with no patients cured who had TURP or radiotherapy in addition to RRP. Preoperative incontinence using pad weight cut-offs of 200 and 400 mL/day, or fewer or greater than 5 pads/ day, was not significantly associated with pad testing or VAS improvement. The results in the report by Cornel *et al.* [40] are less favorable than in those in Gozzi *et al.*'s series [39]. The reason for the discrepancy between the series is unclear, but Cornel *et al.*'s study does suggest that patients who have had TURP or radiotherapy may not benefit from transobturator sling placement based on the definitions used for successful outcome in their study. Additionally, it is important to note that when compared to continence results with AGUS, outcomes reports with male slings have been widely variable and difficult to interpret owing to small, single-center studies with short follow-up periods and variable definitions of success.

Patient selection and evaluation

Careful evaluation and patient selection is important when considering treatment of male urinary incontinence with a male sling. Candidates should be at least 1 year post prostatectomy and have mild-to-moderate SUI. Features that might be predictive of failure should be considered, including high-volume incontinence, comorbidity, and urgency component to the incontinence. Caution should be exercised when considering treatment of patients who have undergone radiation therapy. All patients should have a careful history taken. Physical examination should be performed for documentation and gross quantification of stress incontinence. Cystoscopy should be performed on all candidates to confirm presence of some sphincteric coaptation, as well as absence of stricture or bladder neck contracture. When history suggests mixed incontinence with urgency, or if neurologic disease exists, urodynamics evaluation should be performed to evaluate detrusor activity. As with all interventions for incontinence, caution should be used when patients have detrusor overactivity.

Detrusor hypocontractility is a contraindication for sling placement, whereas for such a patient an AGUS may still be appropriate. Recurrent nephrolithiasis, urothelial carcinoma, unstable stricture disease, or other conditions requiring frequent transurethral access are contraindications to sling placement. Additionally, patients who have previously undergone incontinence surgery with either a sling or AGUS may be more likely to benefit from AGUS than a sling [41]. Patients with risk factors for sling failure, including severe stress incontinence or history of radiation therapy may be better served by AGUS than a male sling. Despite these risk factors, however, male slings may be indicated in otherwise appropriately selected patients with insufficient hand function to operate an AGUS.

In the absence of risk factors for sling failure, many patients may benefit from either a sling or AGUS and should understand the merits of each in the process of making an informed decision.

Surgical technique

Placement of bone-anchored slings will be described, but emphasis is given to the placement of the more commonly used transobturator male slings.

InVance bone-anchored slings

The appropriately chosen patient is positioned under general anesthesia in the high dorsal lithotomy position with the perineum prepped and draped. A 14F urethral catheter is placed for bladder drainage and urethral identification. A 4-cm midline perineal incision is made over the urethra after palpating the catheter and ischial tuberosities. Dissection is carried down over the urethra, leaving the bulbospongiosus muscle intact. Dissection is directed laterally until the pubic tubercle and descending pubic rami are identified. The inferior aspects of the pubic rami are identified. A Scott/Wilson or similar retractor is placed into the incision for exposure. The applicator is used to insert six 5-mm titanium screws as bone anchors into the pubic rami. Three bone anchors are placed 1 cm apart into each descending ramus, just inferior to the pubic symphysis. The most inferior bone anchor should be placed no more inferiorly on the descending ramus than at the level of the bulbar urethra. Each bone anchor is pre-attached to a 1 Prolene suture. An audible change in pitch indicates that the anchor has been inserted to the appropriate depth. The sling is a 4 × 7 cm sheet of pliable mesh composed of silicone-coated multifilament polyester known as InteMesh. The mesh may be trimmed to fit the patient in some cases. One side of the mesh is first tied down snugly with the Prolene sutures attached to the bone anchors in one pubic ramus. Sutures should be placed at least 1-cm medially from the edge of the mesh to provide optimal strength. The second side of the mesh is similarly tied down tightly using the Prolene sutures attached to bone anchors on the second pubic ramus. The mesh should be tied down as tightly as possible to provide maximum tension. An alternative involves intraoperative leak point determination to determine the appropriate mesh tension prior to tying down the second side of the mesh. The perineal incision is closed in three layers using two layers of 3-0 Vicryl and skin with 4-0 chromic suture to complete the procedure.

AdVance transobturator slings

The patient is positioned in high dorsal lithotomy position under general anesthesia. A 14F urethral catheter is placed for bladder drainage and urethral identification. A midline perineal incision is made (Figure 146.3) and carried down to the bulbar urethra, which is identified by palpation of the catheter. The bulbospongiosus muscle is left intact (Figure 146.4). A self-retaining Scott/Wilson retractor is placed into the incision for exposure. Two separate stab incisions are made bilaterally 1 cm inferior to the adductor longus tendon, at the approximate level of the base of the penis. An introducing trocar is passed through one of the stab incisions. The obturator ring is encountered with the trocar, which is then

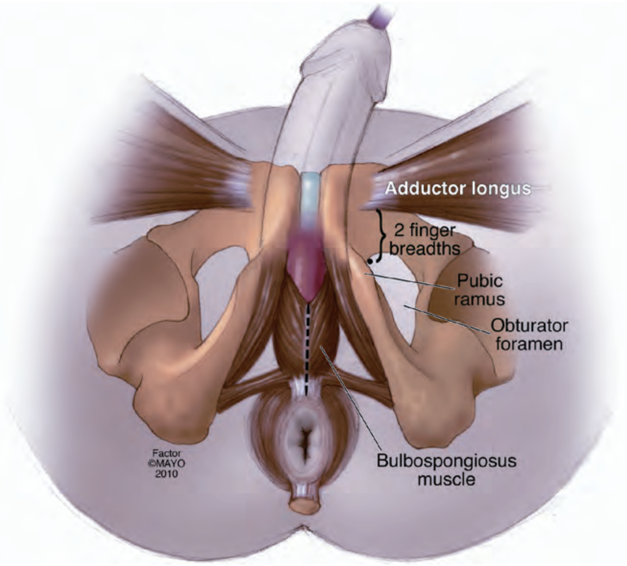

Figure 146.3 Relevant pelvic anatomy for placement of a transobturator male sling. A midline perineal incision is made. Bilateral stab incisions are made two finger breadths posterior to the adductor longus tendon at the level of the base of the penis.

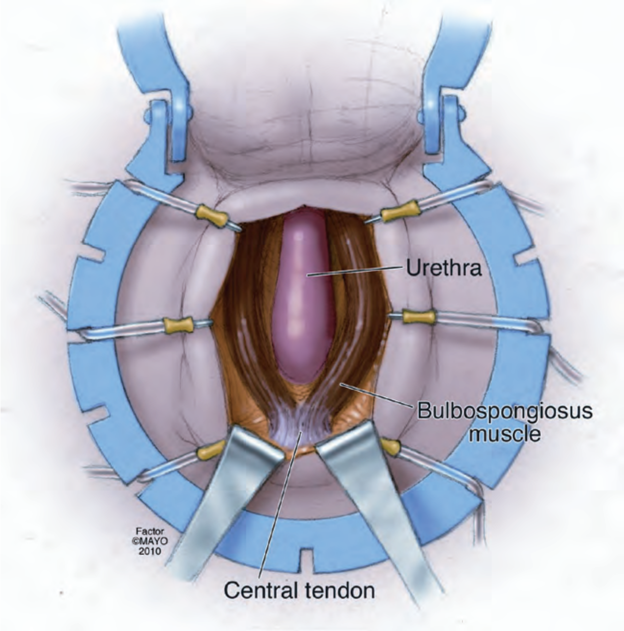

Figure 146.4 Urethra is identified within the midline perineal incision. The bulbospongiosus muscle is spared. A self-retaining retractor is placed into the incision for exposure.

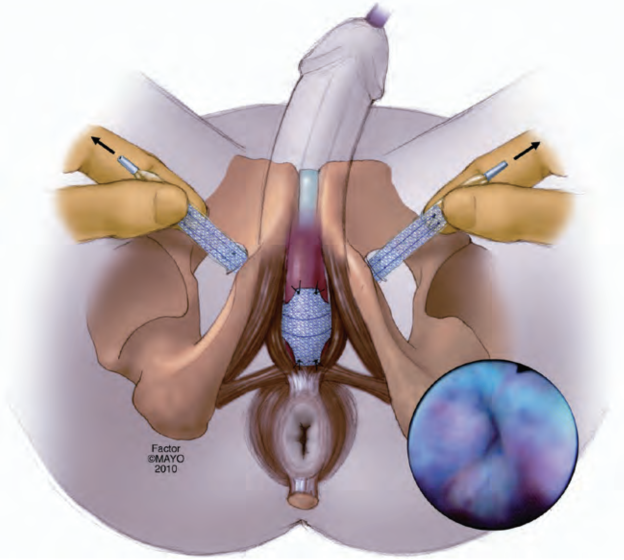

Figure 146.6 Mesh is placed flatly against the urethra and anchored in four corners with 3-0 Vicryl suture. Urethroscopy is performed, and tension is applied to the ends of the mesh under urethroscopic vision to confirm appropriate coaptation of the sphincteric urethra.

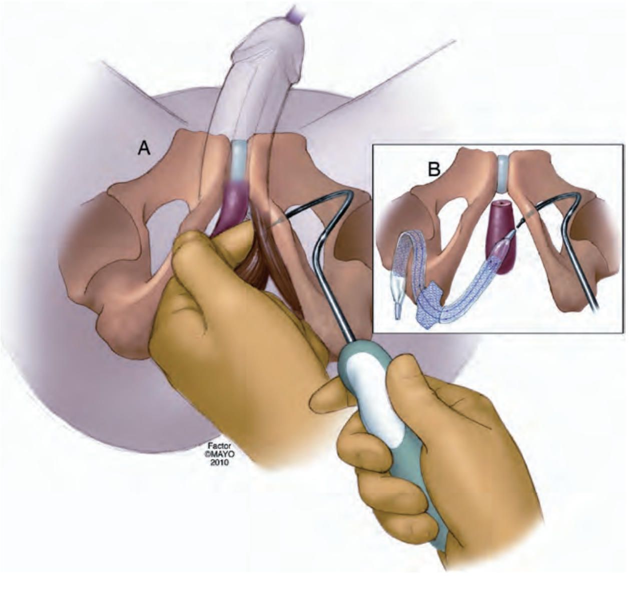

Figure 146.5 (A) A curved trocar is placed through the stab incision. The descending pubic ramus is encountered and the trocar then angled laterally and passed through the obturator ring with index finger guidance. The trocar follows the index finger into the perineal incision. This process is then repeated on the contralateral side. (B) Each end of the AdVance sling is then attached to a trocar eye and brought out through the stab incision.

advanced medially and passed through the obturator membrane and ring. An index finger is used through the perineal incision to guide the trocar out through the perineal incision. A second trocar is then passed through the contralateral stab incision in the same manner. The distal ends of the sling are passed through the eye of each trocar and brought out with each trocar through the stab incisions (Figure 146.5). The mesh at the center of the sling is placed flatly against the sphincteric urethra. Cystoscopy is performed to exclude urethral or bladder injury. Tension on the sling is adjusted under direct vision using urethroscopy so that a bulge is noted at the sphincteric urethra without obstruction of the lumen (Figure 146.6). The mesh is then fixed to the bulbospongiosus muscle overlying the bulbar urethra using one 3-0 Vicryl suture at each corner. Sleeves are removed from the ends of the mesh, and using a right angle, the distal ends of the sling and attached suture are tunneled out of separate stab incisions approximately 2 cm inferomedial to the initial stab incisions bilaterally. Sleeves are removed from the arms of the sling, and the excess mesh is excised (Figure 146.7). Stab incisions are closed with simple 4-0 Vicryl suture. The perineal incision is then closed using two layers of 3-0 Vicryl and skin using 4-0 chromic suture (Figure 146.8). Oral antibiotics are prescribed for 1 week, and strict activity restrictions are

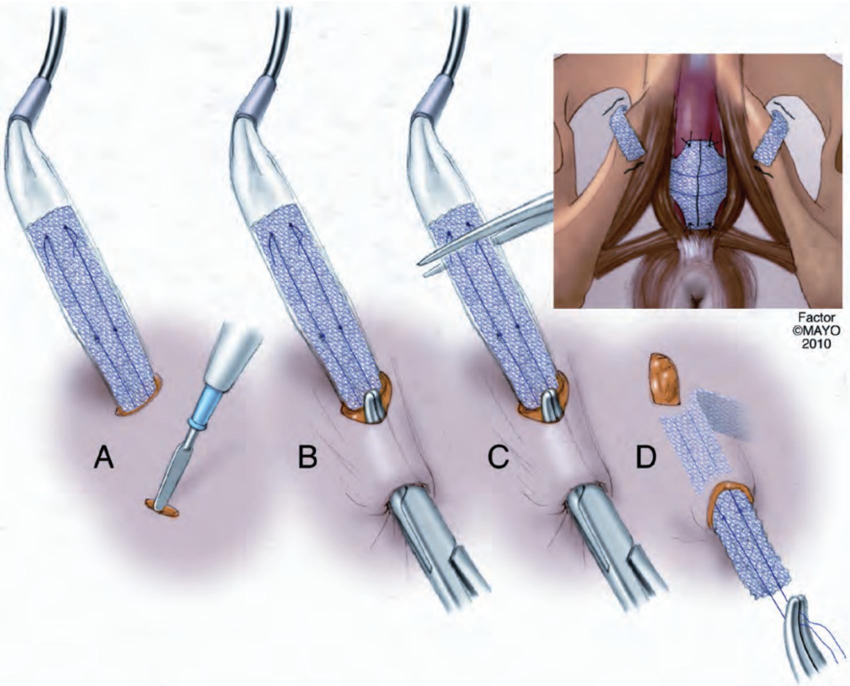

Figure 146.7 (A, B) A superficial stab incision is made 2 cm inferomedial to the stab incision bilaterally. (C) Sleeves are removed from each side of the mesh. (D) A right angle is used to create a tunnel and bring the mesh ends out through the inferomedial stab incisions. Excess mesh is trimmed at skin level.

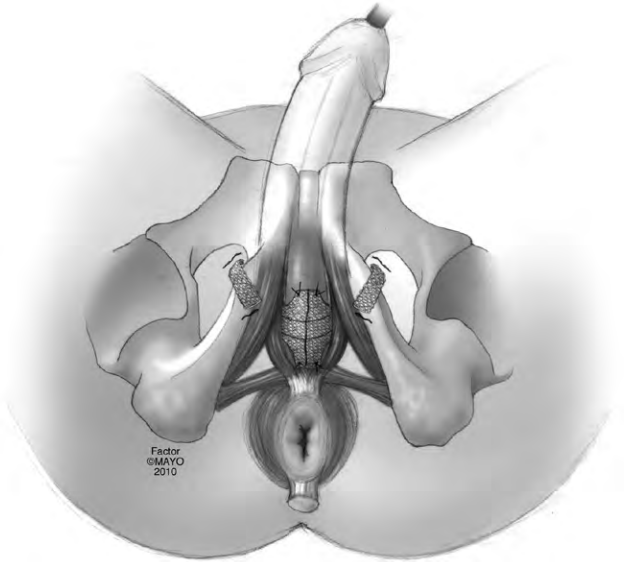

Figure 146.8 Stab incisions are closed with simple interrupted absorbable suture and the perineal incision in three layers with running absorbable suture.

implemented, including no hard chairs, biking, sexual activity, or lifting more than 10 lb for 2–3 months.

Coloplast Virtue male sling

The Coloplast Virtue® sling involves mesh that is fixed to two prepubic arms as well as two transobturator arms in order to provide quadratic fixation of the sphincteric urethra (Figure 146.9). This system is designed to employ principles of both urethral elevation and compression in order to improve post-prostatectomy continence.

Conclusions

Advances in the diagnosis, management, and treatment of men with SUI have resulted in various surgical options. A meticulous preoperative evaluation and long-term analysis of outcomes and results will provide insights into success following sling surgery.

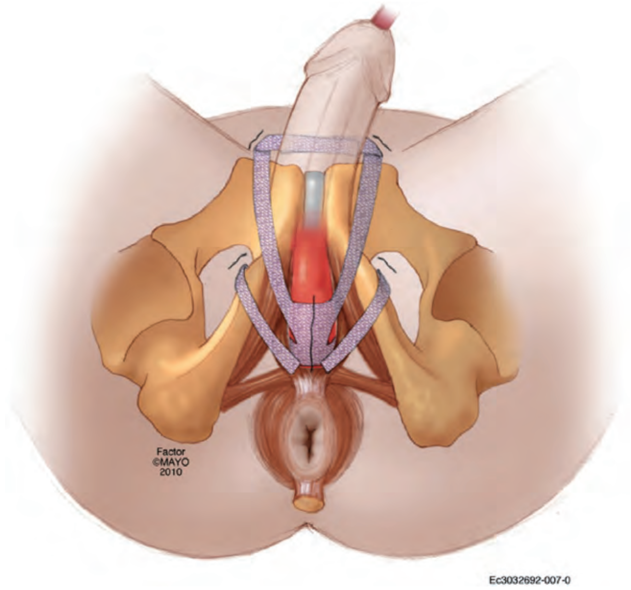

Figure 146.9 Coloplast Virtue® Male Sling.

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